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(b)(1) (A) specifically authorized under criteria established by an Executive order to be kept secret in the interest of national defense or foreign policy and (B) are in fact properly classified to such Executive order;

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(b)(3) specifically exempted from disclosure by statute (other than section 552b of this title), provided that such statute(A) requires that the matters be withheld from the public in such a manner as to leave no discretion on issue, or (B) establishes particular criteria for withholding or refers to particular types of matters to be withheld;

(b)(4) trade secrets and commercial or financial information obtained from a person and privileged or confidential;

(b)(5) inter-agency or intra-agency memorandums or letters which would not be available by law to a party other than an agency in litigation with the agency;

(b)(6) personnel and medical files and similar files the disclosure of which would constitute a clearly unwarranted invasion of personal privacy;

(b)(7) records or information compiled for law enforcement purposes, but only to the extent that the production of such law enforcement records or information (A) could be reasonably be expected to interfere with enforcement proceedings, (B) would deprive a person of a right to a fair trial or an impartial adjudication, (C) could be reasonably expected to constitute an unwarranted invasion of personal privacy, (D) could reasonably be expected to disclose the identity of confidential source, including a State, local, or foreign agency or authority or any private institution which furnished information on a confidential basis, and, in the case of record or information compiled by a criminal law enforcement authority in the course of a criminal investigation, or by an agency conducting a lawful national security intelligence investigation, information furnished by a confidential source, (E) would disclose techniques and procedures for law enforcement investigations or prosecutions, or would disclose guidelines for law enforcement investigations or prosecutions if such disclosure could reasonably be expected to risk circumvention of the law, or (F) could reasonably be expected to endanger the life or physical safety of any individual;

(b)(8) contained in or related to examination, operating, or condition reports prepared by, on behalf of, or for the use of an agency responsible for the regulation or supervision of financial institutions; or

(b)(9) geological and geophysical information and data, including maps, concerning wells.

SUBSECTIONS OF TITLE 5, UNITED STATES CODE, SECTION 552a

(d)(5) information compiled in reasonable anticipation of a civil action proceeding;

(j)(2) material reporting investigative efforts pertaining to the enforcement of criminal law including efforts to prevent, control, or reduce crime or apprehend criminals;

(k)(1) information which is currently and properly classified pursuant to an Executive order in the interest of the national defense or foreign policy, for example, information involving intelligence sources or methods;

(k)(2) investigatory material compiled for law enforcement purposes, other than criminal, which did not result in loss of a right, benefit or privilege under Federal programs, or which would identify a source who furnished information pursuant to a promise that his/her identity would be held in confidence;

(k)(3) material maintained in connection with providing protective services to the President of the United States or any other individual pursuant to the authority of Title 18, United States Code, Section 3056;

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(k)(5) investigatory material compiled solely for the purpose of determining suitability, eligibility, or qualifications for Federal civilian employment or for access to classified information, the disclosure of which would reveal the identity of the person who furnished information pursuant to a promise that his/her identity would be held in confidence;

(k)(6) testing or examination material used to determine individual qualifications for appointment or promotion in Federal Government service the release of which would compromise the testing or examination process;

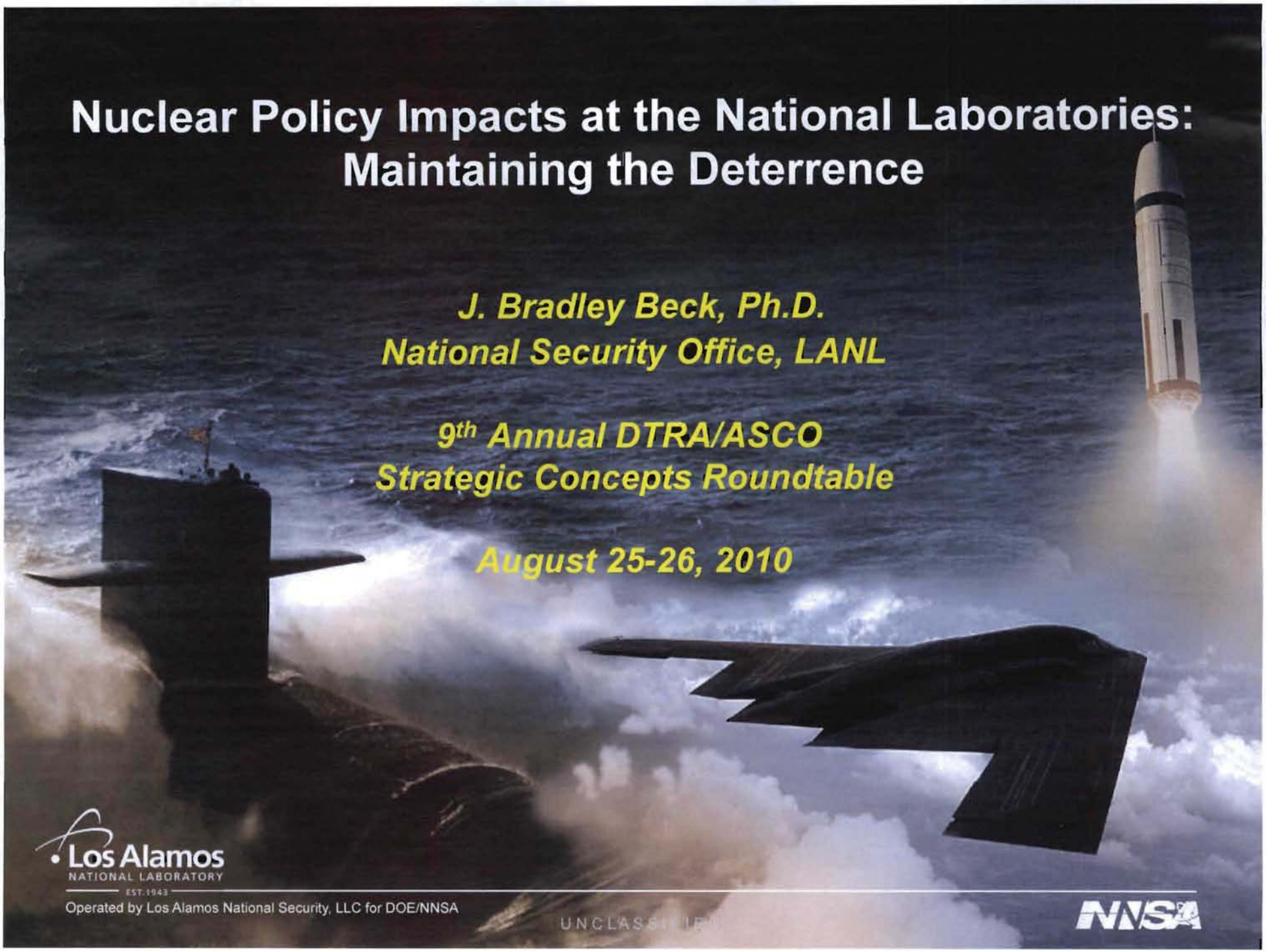
(k)(7) material used to determine potential for promotion in the armed services, the disclosure of which would reveal the identity of the person who furnished the material pursuant to a promise that his/her identity would be held in confidence.

Nuclear Policy Impacts at the National Laboratories: Maintaining the Deterrence

J. Bradley Beck, Ph.D.
National Security Office, LANL

9th Annual DTRA/ASCO
Strategic Concepts Roundtable

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The President and the Administration have a vision for the nuclear security for the United States (U)



...as long as [nuclear] weapons exist, the United States will maintain a safe, secure, and effective arsenal to deter any adversary, and guarantee that defense to our allies..."

President Obama, Prague, April 2009

"[New START] ... maintains the flexibility ... we need to protect ... our national security and to guarantee our unwavering commitment to the security of our allies"

President Obama, Announcement of New START treaty, March 2009

"The NPR calls for ... much-needed investments to rebuild America's aging nuclear infrastructure ... I ... thank ... the Departments of Defense and Energy, including the national labs, [for] sustaining our nuclear arsenal."

Secretary Gates, Preface to NPR Report, April 2010

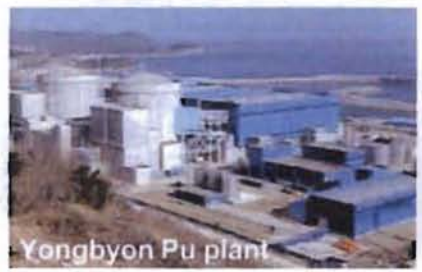














Possible Deterrence Failures

- Deterrence failure:
  - *When we do **not** deter an attack*
  - *WMD attack*
  - *Conventional weapons attack*
  - *When our friends and allies lose confidence in extended deterrence*
- Challenge: make sure this does not occur
  - *Use of technology is important (detection, forensics, …)*
  - *US maintains viable deterrent capability*







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National Security Information

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Weapons N E States Assessments Intelligence Brief

17998

Denuclearizing Ukraine: Potential Bumps in the Trilateral Road (U)

Charles J. Ball
and
Mark A. Warmerdam

COVD-95-0278
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96-347

March 1995

Abstract

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[14] *Grozniy—Ukrainian Reaction*, State Cable 281557Z December 1994, American Embassy, Kiev. (C)

[15] Were Crimea to erupt, Russia could be drawn into a violent conflict which would almost certainly produce a negative effect on Trilateral implementation. (U)

Secretary of Defense Richard B. Cheney, November 12, 1991 remarks to the San Diego Union editorial board

" Unfortunately, if you look at the historic record, we have never, ever gone through one of these periods and gotten it right. We've always screwed it up. Every single time when it's happened previously we've been so quick to cash in the peace dividend, to demobilize that force, that within a very short period of time we find that our weakness in and of itself becomes provocative and tempts others to do things they shouldn't attempt; that we always end up having, once again, to commit the force some place – we get in trouble in the world and have to send in troops; that we find ourselves with troops that are not well trained or well equipped, not prepared to go to war."

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Guard against failure of SLBM warheads (U)

[Trident SLBM warheads are W87 and MIRVed W76. W88 is high hield but big and heavy, whereas W76 is small and only 100 kt so you can pack multiple W76 warheads on each SLBM missile "bus".]

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Sigma 3

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The Future of Non-Strategic Nuclear Forces

Are These Capabilities Still Needed? (U)

Joseph S. Howard II
Edward I. Whitted

April 30, 1991

[Strategic weapons like W76 deter use of nuclear weapons; tactical W79-1 nuclear weapons deter conventional war]

[WHY WE NEED CREDIBLE, TACTICAL NEUTRON BOMB W79-1 TO DETER CONVENTIONAL WARS]

[Reagan put neutron bomb W79-1 in Europe after Russia invaded Afghanistan, and the Warsaw Pact was deterred, but W79-1 was dismantled in 1992, before US & UK signed a 1994 Chamberlain-type "Budapest Memorandum" to guarantee the security of Ukraine if it gave up nuclear arms.]

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W79-1 neutron bomb killed the Warsaw Pact

The Future Of Non-Strategic Nuclear Forces

Are These Capabilities Still Needed? (U)

by

Joseph S. Howard II
Edward I. Whitted

ABSTRACT (U)

The epochal political events of 1989–1990 are greatly influencing US non-strategic nuclear forces (NSNF). NATO NSNF strategy is undergoing revision. The London Communique of July 6, 1990 is the harbinger of an intense debate upon future NATO nuclear roles and missions. The President's cancellation of the Follow-on-to-Lance missile (FOTL) and the offer of withdrawal of forward-deployed nuclear cannon projectiles to NATO indicate downward trends in future NSNF stockpiles.

This report, in the form of an executive summary and an annotated briefing, presents the results of a yearlong policy and systems analysis investigation. The authors examine plausible rationale, first principles, that govern the justification for future NSNF. They then assess the capabilities of reduced stockpiles during 1995–2000 wherein regional powers may possess nuclear arms. By configuring three nuclear scenarios in which US vital interests are at stake, the authors analyze the number of NSNF weapons to investigate "how much NSNF is enough?" They also examine implications to the US Army should downward trends in short-range nuclear forces continue.

EXECUTIVE SUMMARY

Background

The world has witnessed such revolutionary changes over the past 18 months that clearly a new era has started. In this context, the authors undertook a study in late 1989 with partial Army support that would assess future European short-range nuclear force (SNF) structures and target sets. The rapidity of the political changes in Europe and the Soviet Union at the early stages of the effort motivated broadening the study to include strike non-strategic nuclear forces (NSNF) in a worldwide context. Also, the nature of the evolving era indicated that a traditional target-based analysis would be sadly deficient without underlying policy and economic assessments. These assessments have led us to conclude that, even more than before, future stockpiles will not be determined strictly on the basis of threat target defeat. Stockpiles will be configured from a complex interaction of domestic and international politics, defense budgets, arms control treaties, and differing threat perceptions.

The events in Europe are also affecting US NSNF strategies for other theaters. The outcome of future Nuclear Weapons Requirements Studies (NWRS) from the nuclear CINCs may profoundly affect NSNF roles and missions of the services. Trends in late 1990 were moving toward a denuclearization of the Army in the sense that organic nuclear systems might be retired.

Therefore, this paper examines the 1995-2000 rationale, roles, and capabilities of US NSNF in light of the revolutionary changes in Europe, plausible future nuclear threats worldwide, and downward trends in NSNF due to economic and political pressures.

Policy Findings: Strong Reasons for NSNF

The strategy and policy reassessment of US NSNF identified strong rationale for a continued role:

- As a visible instrument of superpower status in an uncertain and unpredictable world

- As a deterrent to future non-superpower nuclear-capable adversaries in a proliferated world

- As a deterrent to regional Soviet or Russian aggression as long as resurgence or reconstitution remains feasible

- To provide stability and insurance in a post-CFE Europe through a small air-delivered, forward-deployed force

Because of European politics, US NSNF structure decisions must be broader than peacetime NATO strategies, policies, and constraints.

The old *raison d'etre* for US NSNF: the Soviet Threat

1. **Democracies and economies of Western Europe**
2. **The overriding threat: the Soviet Union**
3. **NATO was unable to provide sufficient conventional forces**
4. **Deployment of nuclear weapons to Europe created an extended deterrence umbrella for conventional force deficiencies**

Other US CINCs were also allocated NSNF for deterrence of the worldwide Soviet Threat

Initially behind the deployment of US forward-based nuclear forces has been the threat of Soviet landpower, and subsequently the Soviets' own theater nuclear capabilities. The victory of the allies in the Second World War led to several unforeseen events: one was the raising of the Iron Curtain in the late 1940s through the subjection of Eastern European countries by the Soviet Union. The US, after fighting a war against totalitarianism, turned to a grand strategy of containment of Soviet imperialism. A free and prosperous Western Europe continued to be of utmost interest to the US; and therefore, the NATO alliance was formed to draw the line against further Soviet expansion. Unfortunately, the Soviet Union and its Warsaw Treaty Organization (WTO) alliance deployed forces far beyond those required for its own defense. Unable and unwilling to match the conventional force goals of the 1952 Lisbon Conference, the US deployed its first theater nuclear weapons for NATO in 1953.

Over the past 45 years, NATO nuclear doctrine has evolved from "massive retaliation" in MC 14/2, to "flexible response" in MC 14/3, then to the development of provisional political guidance (PPG) for initial and follow-on nuclear use, next to the Montebello modernization decisions, and now to the proposed "weapons of last resort" from last summer's London communique. But behind all of these declaratory doctrines and revisions, excepting the last, has been the massive Soviet threat.

The US strategy of extended deterrence, operative with the forward-deployment of US weapons and nuclear guarantees to the allies, has created a tension between the Europeans and the US. The presence of US weapons in Europe has been emphasized by the Europeans as a coupling to the US Central Strategic Forces. Hence, the specter of Armageddon must always reside in the calculus of the Soviet Union. Conversely to the US, the presence of theater nuclear weapons (now NSNF) gave an aura of credible response options before the ultimate response.

But Future Regional Threats dictate three NSNF Deterrent Rationales broader than European stability forces

War prevention and war termination where US vital interests are involved:

2. A visible symbol of national power in an uncertain & unpredictable multipolar world

3. A deterrent to future non-superpower nuclear-capable adversaries in a proliferated world

4. A deterrent to regional Soviet or Russian aggression as long as resurgence or reconstitution remains feasible.

NSNF Roles

- **An incalculable risk to the threat(s)**
- **Appropriate & credible non-strategic nuclear options including capabilities for in-kind nuclear response**
- **Direct defense of endangered US forces**

The first major rationale for NSNF derives from its contribution as a political instrument and an insurance policy for the superpower US Although not often on center stage in a number of regional disputes or conflicts, NSNF availability in the wings has certainly played an important role in diplomatic interchanges and crises.

A future nuclear-proliferated world would present enormous challenges to US defense interests. Over ten nations possess the capabilities to obtain nuclear armaments in the next decade. Several of these nations maintain profoundly hostile relations to the US As regional powers in their own right with significant conventional armaments, their addition of nuclear capability would raise grave risks to deployed US forces.

While the aggressive intentions of the Soviet Union towards Europe may have disappeared, their conventional and nuclear capabilities remain huge. While the short-warning scenarios are no longer credible, a future resurgent and mobilized Soviet Union remains feasible. While intentions can move towards amicability, they can subsequently be reversed upon change in leadership. The Soviet Union or the greater Russian Republic, should some republics become autonomous, may have future cause to counter US vital interests in critical regions such as Southwest Asia, despite present trusts.

Therefore, we are incredulous of US forces without NSNF to prevent war or to terminate war against hostile nuclear-armed states. The rationale for NSNF must rest upon its capabilities to deter a plausible resurgent Soviet Union, or any of several regional powers with potential nuclear capabilities. As NSNF kept the long peace in Europe because it engendered cautious behavior, so should NSNF be kept as an incalculable risk towards any nuclear state contemplating aggression.

The rationale for NSNF also involves the element of credibility: the NCA should have options other than central strategic forces for an appropriate response.

Current and programmed force systems provide a span of yields and ranges

DOE b(3)

- TLAM N with W80-0 [redacted]
- AF DCA with B61 Mods (3,4,5,9,10) or new TASM [redacted]
- Navy DCA with B61 Mods (5, 6, 8) and B90 NDSB [redacted]
- AF F-15E/F-111 with W91 SRAM T [redacted]
- Army Ground Systems - 8-in W79-0 and W79-1 [redacted]

Ranges & radiuses DoD b(1) deletions EO 1.5 (a), (c) & (e),

1990 planning documents of current and projected forces show a force with a wide span of yields and ranges. However, more realistic future projections cloud their availability.

DOE b(3) [redacted]

DOD b(1) EO 1.5(a) Another example would be early retirement of the W79. The W79-1 enhanced radiation warhead is very effective against troop formations. Many DCAs delivering gravity bombs would be needed to substitute, probably inadequately, for this capability loss.

A third example would be the cancellation of the SRAM T. Our subsequent analyses reveal that the additional demands on TLAM-N and penetrating DCAs would be unrealistically high. An option, should this come about, might be a common system which can be delivered by

Future NSNF options can be more limited in scope

1. Initial Use Options:
   - Credibly deter or respond to limited threat nuclear use
   - Defeat the most important war-supporting and projection force assets

2. Follow-on to Initial Use Options
   - Credibly deter or respond to threat nuclear use
   - Prevent overrun of committed US forces

3. Selective Employment Options
   - Credibly deter or respond to wider threat nuclear use
   - Defeat high-priority fixed targets, defeat maneuver divisions

[redacted] DoD b(1) EO 1.5(a),(c),(e),(g)

Unquestionably the number of potential NSNF targets has fallen dramatically.

[redacted] DoD b(1) EO 1.5(a) (e) (c) (g)

Notwithstanding, we think that CONUS-based US NSNF must be configured to meet operational requirements against potential threats: specifically a reconstituted Russian threat and two third-world nuclear threats at the same time.

[redacted] DoD b(1) EO 1.5(a) (e),(c),(g)

Under the three categories of options would be the mission to credibly deter aggression or respond to threat nuclear use. The traditional rationale of deterrence or restoration of deterrence would hold: war prevention and if need be, war termination.

Capabilities analysis assumptions

- Probability of Arrival = 1
- Probability of Defeat/Damage (PD) ≥ 0.90 required for fixed targets; 50% defeat of mobile target essential combat elements
- Moderate fixed target damage VNTK; 30% mobile unit coverage at 3000 cGy
- Fixed target density is uniformly distributed
- All targets treated equally & independently with only one weapon per target; I. e., PD = PSSK ≥ 0.90
- Maximum combat radius (HI-Low-Low-HI flight profile) and delivery accuracies

DoD and DoE b(1) EO 1.5(a)(c)(e)(g)

[redacted]

In general, we used a typical methodology and standard assumptions to arrive at stockpile requirements against the target sets.

The methodology assumed 100% reliably arriving weapon systems, one weapon per target, target elements uniformly distributed, and a 90% probability of single shot kill (PSSK). The target defeat criteria consisted of moderate VNTK damage on fixed targets and 50% defeat of a division's essential combat elements (ECEs). An ECE was considered defeated when 30% of its elements were covered by at least 3000 cGy (immediate transient incapacitation) by the effects of the W79-1 or a B61 bomb.

DoD and DoE b(3) FRD

[redacted]

V. SUMMARY

Force Rationale
- Past rationale
- Start of a new epoch
- Determinants of a future US NSNF strategy

Force Assessment
- Roles and attributes
- Systems
- Numbers

Force Structure
- Army SNF
- SRAM T

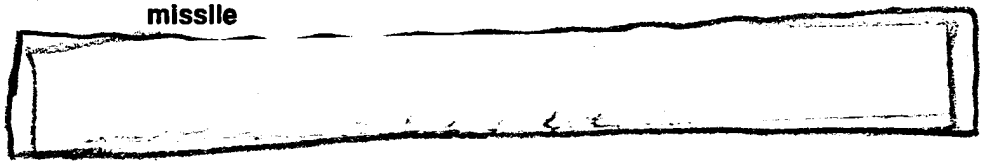
Summary
- Findings
- Recommendations

The final section of this paper concludes with a summary of the previous findings; and based upon these findings, offers recommendations.

Recommendations

1. **Army should keep an organic capability**
   - **Maintain the W79 and 8-inch delivery as an interim system**
   - **At the appropriate time (suggest two years) initiate a study to**
     - Formally assess future Strategic Army battlefield nuclear missions
     - Examine organic Army force structure alternatives
     - Define technical options for future nuclear systems
2. **Air Force should develop a theater air-delivered stand-off missile**

DoD b(3) FRD



We make the above three recommendations based upon the essential findings of this study.

ACKNOWLEDGEMENTS

Many defense analysts graciously gave of their time in listening and commenting on earlier versions of this work. The nature of the policy analysis required us to use a non-attribution approach; therefore we will not generally recognize individuals who provided substantial information. However, special thanks are given for the support of Bob LaRocque, Ron McGee, Major Jeff Geoque, and Peggy Fratzl at TRAC-Leavenworth who provided invaluable programmatic and technical assistance to make this project possible.

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History of Gun-Type Artillery-Fired Atomic Projectiles

Mk 9 Shell

The possibility of developing an artillery-delivered gun-type atomic device was discussed in late 1949 by Army Ordnance. This shell would be a defensive or offensive weapon against infantry masses concentrated in front of the sector through which a breakthrough was planned. It was hoped that a nuclear artillery shell, fuzed for air burst, could destroy the ability of these troops to stage an attack, or to defend the sector.

Possible delivery methods considered for such a weapon included railway rifles, guided missiles, aircraft, or artillery field pieces. Railway rifles, besides being almost obsolete, were ruled out due to heavy weight and relative immobility. Guided missiles capable of carrying atomic warheads were not as yet available. Bombing inaccuracy and difficulty in identifying battlefield targets made use of aircraft-delivered weapons unattractive.

It was felt, however, that artillery field pieces could be used, at least until suitable guided missiles became available. Army Ordnance had developed a mobile gun of 240-mm diameter (about 9-1/2 inches), weighing 90 tons, which was soon to be proof-fired, and a conference was held with Los Alamos Scientific Laboratory personnel November 10, 1949, at which use of this gun was advocated. The nuclear designers stated that a gun-type nuclear device would fit inside a 240-mm gun barrel, although concern was felt about the relatively inefficient usage of fissionable material in such an assembly.[1]

Another meeting was held on the same subject January 16-17, 1950. Increased Los Alamos interest in the project had developed, and Army Ordnance representatives discussed possible shell designs. One proposal was to develop a 240-mm-diameter shell, to fit the mobile gun, and another was to install a 280-mm barrel on the 240-mm mount, thus allowing the shell diameter to increase to about 11 inches.[2]

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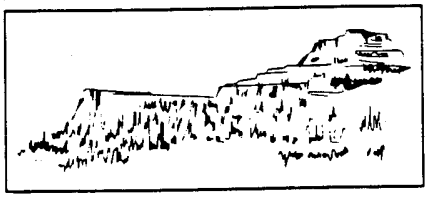
A Review of the Development of Los Alamos Gnats and Tsetses before the 1958 Test Moratorium (U)

Lawrence S. Germain

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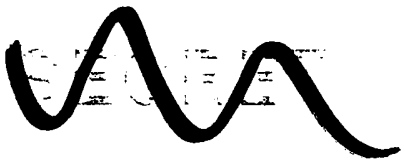
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Lawrence S. Germain retired from the Los Alamos National Laboratory in 1985 after thirty years of experience in weapons design and testing in the national laboratories—twenty years at Lawrence Livermore National Laboratory and ten years at Los Alamos. He received a Ph.D. in physics from the University of California, Berkeley, in 1949 and taught physics for four years at Reed College, Portland, Oregon, before joining Livermore. Much of this report is drawn from the author's memory, and many of the opinions expressed reflect his personal recollections.

The first draft of this report was written in 1988, and the information in the report does not reflect events or research since 1988.



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Critical Nuclear Weapon
Design Information
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A Brief History of the First Efforts of the Livermore Small-Weapons Program (U)

Lawrence S. Germain

January 2, 1991

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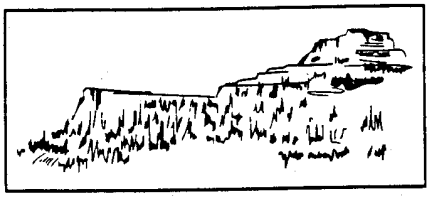
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PREFACE

This report is one in a CNSS series that surveys the development of nuclear weapons over the past forty-five years. The unifying themes throughout the series are the technical advances and failures associated with new weapon systems, and the creation of the stockpile.

Authors, titles, and report numbers are listed below.

William G. Davey, *Free-Fall Nuclear Bombs in the U.S. Stockpile (U)*, LA-11397

William G. Davey, *Nuclear Tests Related to Stockpiled Weapons Development (U)*, LA-11402

Lawrence S. Germain, *A Brief History of the First Efforts of the Livermore Small-Weapons Program (U)*, LA-11404

Lawrence S. Germain, *The Evolution of U.S. Nuclear Weapons Design: Trinity to King (U)*, LA-11403

Lawrence S. Germain, *A Review of the Development of Los Alamos Gnats and Tsetses before the 1958 Test Moratorium(U)*, LA-11749

Raymond Pollock, *The Evolution of the Early Thermonuclear Stockpile (U)*, LA-11748

Raymond Pollock, *A Short History of the U.S. Nuclear Stockpile 1945–1985 (U)*, LA-11401

(All reports are classified Secret Restricted Data)

DoE b(3)

Rainier was detonated on September 19, 1957, in a tunnel in Area 12. Rainier also gave its name to the mesa into which the tunnels were dug (Rainier Mesa) and to the volcanic rocks that cap that mesa (Rainier Mesa Tuff).

DoE b(3)

58A

As more and more weapons entered stockpile and came into the hands of people less knowledgeable about nuclear design, questions about the safety of nuclear weapons assumed more importance. One of the first questions to receive serious attention was one-point safety. The requirement was that no more than four pounds of nuclear yield should be produced as a result of the detonation at *any* one point in the HE, perhaps because four pounds is small compared with the amount of HE in the various devices.

The design physicist was repeatedly scolded for presenting unpromising results. He was urged to make the system work. As a result, he took the most optimistic view of each of the several areas of uncertainty in the design—too optimistic, as it turned out. It was only the nuclear test that revealed the overly optimistic approach. In the absence of nuclear testing, the design errors might never have been uncovered.

DoE b(3)

If there were no tests to keep the system honest, nuclear designers could be pressured into certifying designs that would not work.

As a consequence of these concerns, a series of one-point tests was conducted at the NTS called Operation 58A, which included two safety tests, Venus and Uranus, of Livermore devices. These were carried out between Operation Plumbbob and Operation Hardtack.

DoE b(3)

DoE b(3)

There were other Livermore tests in Operation Plumbbob to which the Livermore Small-Weapons Group did not contribute.

DoE b(3)

DoE b(3)

DoE b(3)

DoE b(3)

DoE b(3)

DoE b(3)

DoE b(3)

DoE b(3)

Quince and Fig were fired on Runit (Yvonne) Island in Eniwetok Atoll as close to the ground as pos-

sible—the standoff of a few inches being required by the device designers to ensure that the presence of the ground did not perturb the implosion. This near-ground test was required to accommodate a fallout experiment conducted by Sandia.

DoE b(3)

DoE b(3)

DoE b(3)

There being no other NTS soil at hand, the Fig device was emplaced in the same location—radiation field or no. The Hamilton test was fired at the top of a 50-ft wood tower in Frenchman Flat, and Humboldt was fired atop a hastily constructed 25-ft wood tower in Area 3 of the NTS.

DoE b(3)

Laboratory interest in small, clean, and relatively clean warheads led to the testing of several unique systems.

DoE b(3)

DoE b(3)

Ref. Sym: 7223(30L)

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XR SYSTEMS FOR OPERATION REDWING

INTRODUCTION

At the request of Los Alamos Scientific Laboratory and University of California Radiation Laboratory, Livermore Site, Sandia Corporation has prepared external initiator equipment for use in Operation REDWING. The external initiator equipment (XR) in general consists of a pulsed neutron source (S-Unit) similar to those used in Operation TEAPOT, designed and constructed by the General Electric X-Ray Department, a time delay circuit designed at Sandia Corporation and a power supply (MC 251 inverter). The purpose of this report is to describe the XR apparatus, systems and applications for Operation REDWING.

Requirements

The following is a summary of the shots for which XR is planned:

Shot Name	Ready Date	Responsible Laboratory	Device Being Initiated
LaCrosse	May 1	LASL	
Inca	June 8	UCRL	
Yuma	June 1	UCRL	
Kickapoo	June 18	UCRL	
Erie	May 23	LASL	
Seminole	May 28	LASL	
Flathead	June 2	LASL	
Blackfoot	June 7	LASL	
Mohawk	July 1	UCRL	
Huron	June 12	LASL	
Apache	July 1	UCRL	
Dakota		LASL	
Pawnee		LASL	

DOE 6(3)

For purposes of XR requirements the shots are broken into three groups. These groups are listed below with associated neutron requirements:

Type Group	Shot Name	Neutron Output per S-Unit	No. of S-Units Required
I			2
I			2
I			2
II			2
II			2
II			2
II			2
III			4
III			4
III			4
III			4
III			4
III			4

DOE 6(3)

Four S-Units may be required

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Probability that the required number of neutrons will be furnished should be at least 95% and confidence level of this probability should be at least 95%.

DOE 6(3)

The exact desired time should be known three days prior to the ready date. This information should be directed to either B. J. Carr or N. J. Elliott, one of whom will be located on Paree Island, Building 415 after April 15, 1956.

Separation of the S-Unit from the HE systems has been left to the responsible laboratory in each case.

XR SYSTEM COMPONENTS

Each of the three XR systems to be used consists of several building blocks. These are (1) the neutron source (S-Unit), (2) the unit "B" junction box, and (3) the XR timer control box with time delay Unit "A". These parts are described in the next three sections.

The S-Unit

The pulsed neutron source unit S to be used in Operation REDWING is the S-5D unit which was developed by the General Electric X-Ray Department for Sandia Corporation. This unit has been described previously in the preliminary TEAPOT reports. It consists of a small pulsed linear accelerator which produces 14 MEV neutrons from an TD reaction.

DOE 6(3)

The entire unit is welded shut and is pressurized with SF_6. An outline drawing is shown in Figure 1. The size of

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EARTH PENETRATOR WEAPON SYSTEM DESIGN

W. J. PATTERSON AND N. A. LAPETINA; SANDIA NATIONAL LABORATORIES

INTRODUCTION

MAJOR EPW SUBSYSTEMS

EPW SYSTEM DESIGN RATIONALE

TEST PROGRAM

WEIGHT REDUCTION



WJP/5165/3-88

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REQUIRED INFORMATION FOR FIRST DESIGN ITERATION

TARGET SET DEFINITION

LOCATION, DEPTH, SIZE AND HARDNESS OF STRUCTURES

SITE GEOLOGY, SOIL AND ROCK MATERIAL PROPERTIES, TOPOLOGY,

POTENTIAL DELIVERY SYSTEMS

ICBM, CRUISE MISSILE, OR GRAVITY BOMB

ESTIMATE OF NUCLEAR YIELD REQUIRED TO DESTROY TARGETS



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EARTH PENETRATOR WEAPON SYSTEM DESIGN

TARGET CHARACTERISTICS THAT IMPACT EPW SURVIVABILITY

HARDNESS

- CONFINED SHEAR STRENGTH (PRESSURE DEPENDENT)
- VOLUMETRIC COMPRESSIBILITY
- DENSITY
- MOISTURE CONTENT

IRREGULARITIES (INDUCE LARGE LATERAL LOADS)

- BUILDINGS
- RUBBLE
- BOULDERS
- TREES
- TARGET NON HOMOGENEITY



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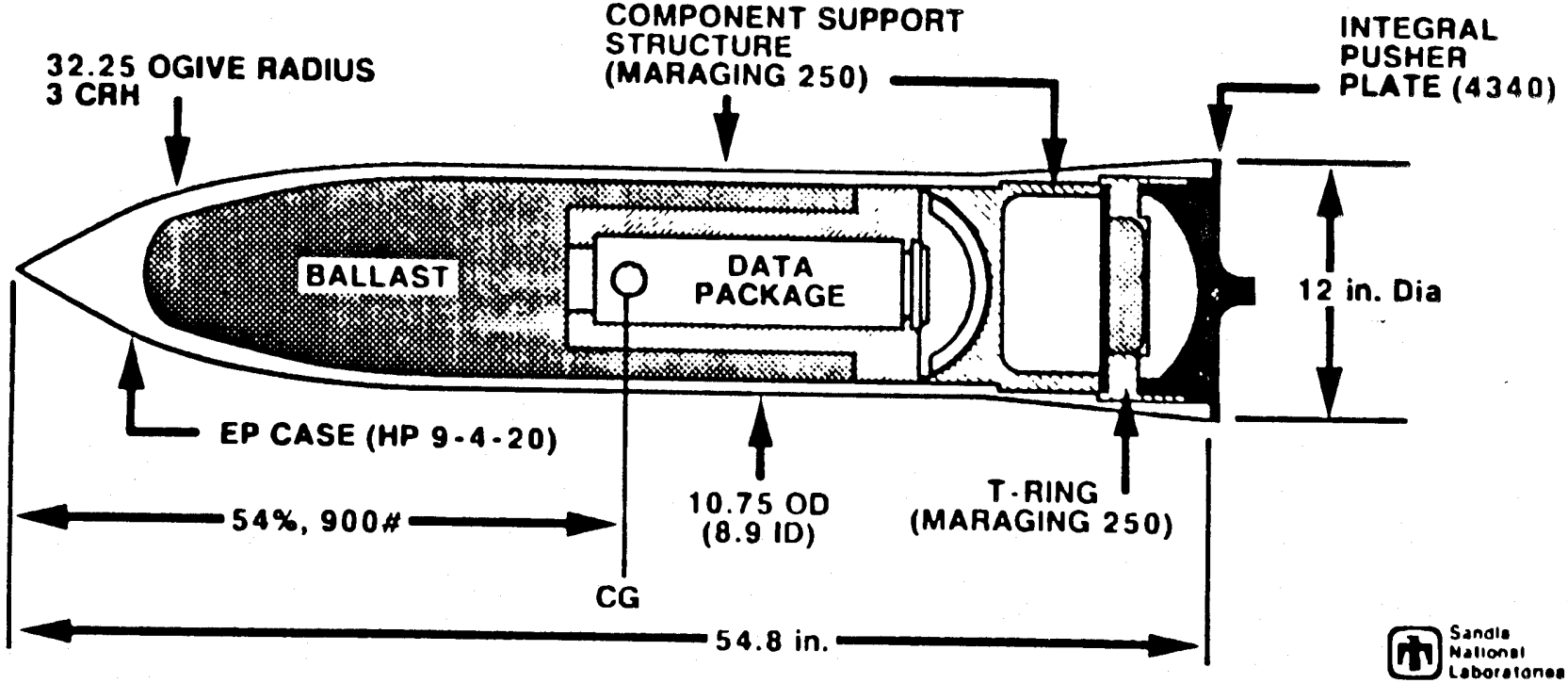
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EARTH PENETRATOR TEST DEVICE

86TH5000.08

PROPERTIES

- L/D = 5.1
- W/A = 9.9
- Wt = 900 lb
- CG = 29.6 in.
- PITCH = 2.1×10^5 lb-in.^{2}



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SANDIA/LOS ALAMOS EPW PROGRAM

HISTORICAL PERSPECTIVE OF ACCOMPLISHMENTS

W86 TACTICAL EPW FOR PERSHING II

APRIL, 1979 – PHASE 3 START

SEPT., 1980 – PHASE 3 CANCELLED

W86 PHASE DOWN PROGRAM & TECHNOLOGY

JAN., 1982 – W86 DEMONSTRATION COMPLETED

DESIGN ON THE SHELF

RV COMPATIBLE EPW DESIGN DEVELOPMENT

SEPT., 1982 – LOW L/D DESIGN TESTED

SEPT., 1983 – LOW L/D DESIGNS SUBMITTED

APRIL, 1985 – LOW L/D HARD ROCK DESIGN TESTED

JAN., 1986 – LOW L/D DESIGN TESTED IN

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Enclosure 1: #58

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Printed November 1988

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Ground Shock from Earth Penetrator Weapons

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AUTHORITY DOE/NN-52
BY R.H. SMILEY
RHS, ADD, 2-22-96

Paul Yarrington

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
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Ground Shock from Earth Penetrator Weapons

Paul Yarrington
Computational Physics & Mechanics Division II
Sandia National Laboratories
Albuquerque, New Mexico

ABSTRACT

This report presents results of calculations to predict ground shock effects from earth penetrating weapons. The study models 500 kiloton explosions at two depths below the ground surface in homogeneous, saturated, soft rock geology. Comparisons of weapon lethal range are made using various free-field damage criteria for near-surface and deeply-buried targets. Comparisons are also made with calculational results for ground shock from above-surface and shallowly-buried selected bursts.

2. Calculational Approach

The calculations reported here were performed with the two-dimensional, Eulerian wavecode, CSQII (version 6/82) [3], assuming cylindrical symmetry about the penetrator axis. The penetrator was modeled as a solid cylinder of iron, 30 cm in diameter and 180 cm long. The center of the penetrator was assumed to be at the nominal depth of burst for each problem. Energy release for the the EPW burst was simulated by uniformly depositing 500 kt (2.1×10^{22} ergs) of energy in the iron cylinder representing the penetrator, with the energy being deposited at a constant rate over a time interval of 20 nanoseconds.

The effects of the penetration event on the target material above the weapon were assumed to be of negligible importance to the energy coupling and ground shock associated with the EPW bursts. Thus, the target medium surrounding the weapon in all directions was modeled as uniform and undisturbed. Air above the ground surface was explicitly modeled in the calculations.

The ANEOS [4] equation-of-state (EOS) package associated with CSQ was used to model the materials in the calculations. A library EOS (ANEOS Library Material No. -5) was used for the iron penetrator, although, given the extremely high temperatures reached by the penetrator materials, the ground shock effects are essentially independent of the material chosen to model the projectile. A tabular EOS (Table No. 1885) was used for the air. The ANEOS input for the tuff is given in Appendix 1, while principal material properties are listed in Table 1. Material properties for the tuff were chosen to be the same as those used in an earlier Sandia calculational study [5] of ground shock effects. Hugoniot and selected release curves generated with the tuff model are shown in Figures 1 and 2.

3. Calculational Results and Description of Phenomenology

Within a few microseconds after the burst, the expanding cavity of vaporized tuff and weapon debris becomes essentially spherical. This can be seen in Figure 3, which shows the 1 Mbar pressure contour for the 6 m DOB problem at 50 microseconds, shortly before the burst breaks through the surface of the ground. Note that the center of burst was at the origin of the coordinate system in both of the EPW calculations. When breakout occurs, energy is rapidly lost from the cavity, as hot, high pressure gases vent to the atmosphere. Figure 4 shows a sequence of early-time pressure contours, where the strong hydrodynamic motions that occur following breakout are evident. Velocity and temperature profiles on axis during this cavity breakout phase of the problem are shown in Figure 5. Histories of total energy in the tuff and in the air are cross-plotted to a problem time of 10 ms in Figure 6, where the rapid, early-time transfer of energy from tuff to air can be clearly seen.

For the deeper burst, these processes occur later in time, and less energy is transferred to the air than for the shallower burst. Figure 7 compares pressure contours for the two EPW bursts at problem times of 2 ms, 6 ms and 10 ms. Figure 8 shows the time history of total energy in the air during the first 30 ms for the two problems. As time progresses, the pressure in the cavity for both bursts drops well below that for a fully-contained explosion [6], as shown in Figure 9.

Figure 10 compares late-time pressure contours for both problems and shows a somewhat stronger ground shock for the deeper burst, as would be expected. This is evident from the wider contours that are seen for the deeper burst at any given stress level. Compare, for example, the 0.5 kb contours (level E) for the two cases.

With the contour levels chosen in Figure 10, the front of a pressure wave can be seen propagating in the air along the ground surface, suggesting that some "airblast" effects may be associated with the EPW bursts. The strength of this blast wave is

greatly reduced, however, from that produced by a surface burst and will decay to negligible levels at ranges where the ground shock is still well above its lethal level. Thus, ground shock is definitely the dominant weapon effect against hardened structures for the EPW bursts simulated here, with "airblast" making virtually no contribution to the overall lethal radius of the weapon.

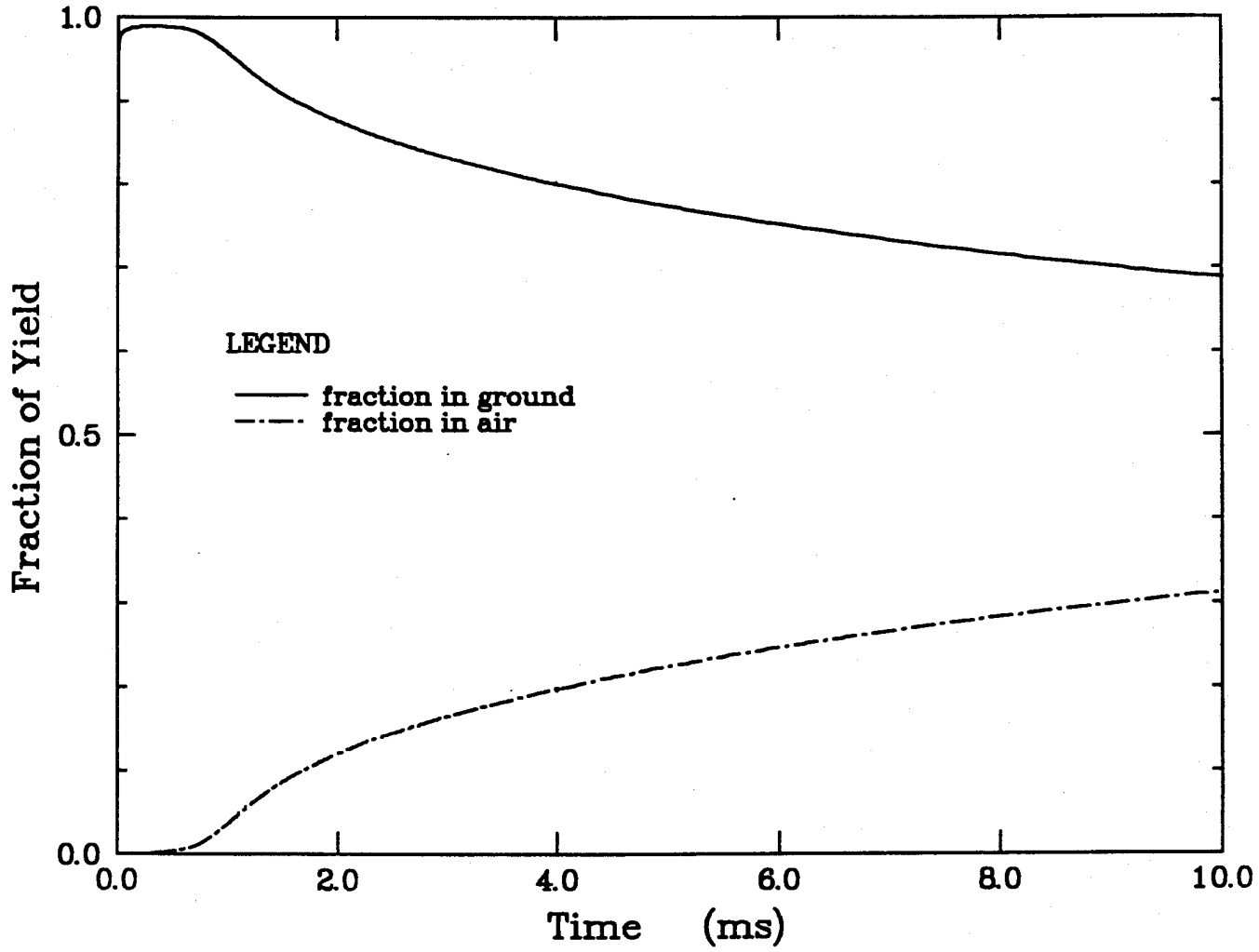


Figure 6: Energy partitioning between ground and air for 6m DOB EPW.

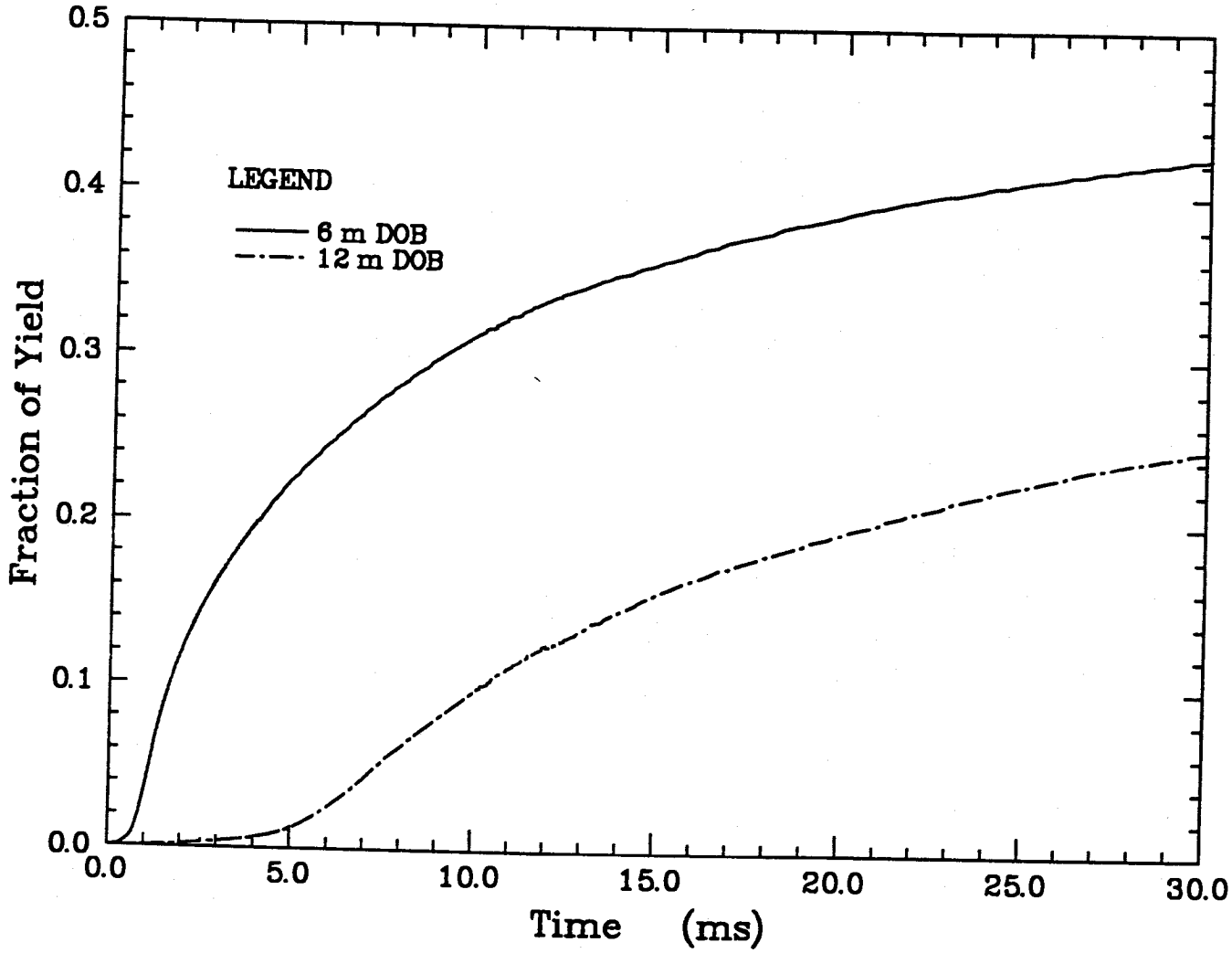


Figure 8: Energy history in air for EPW bursts.

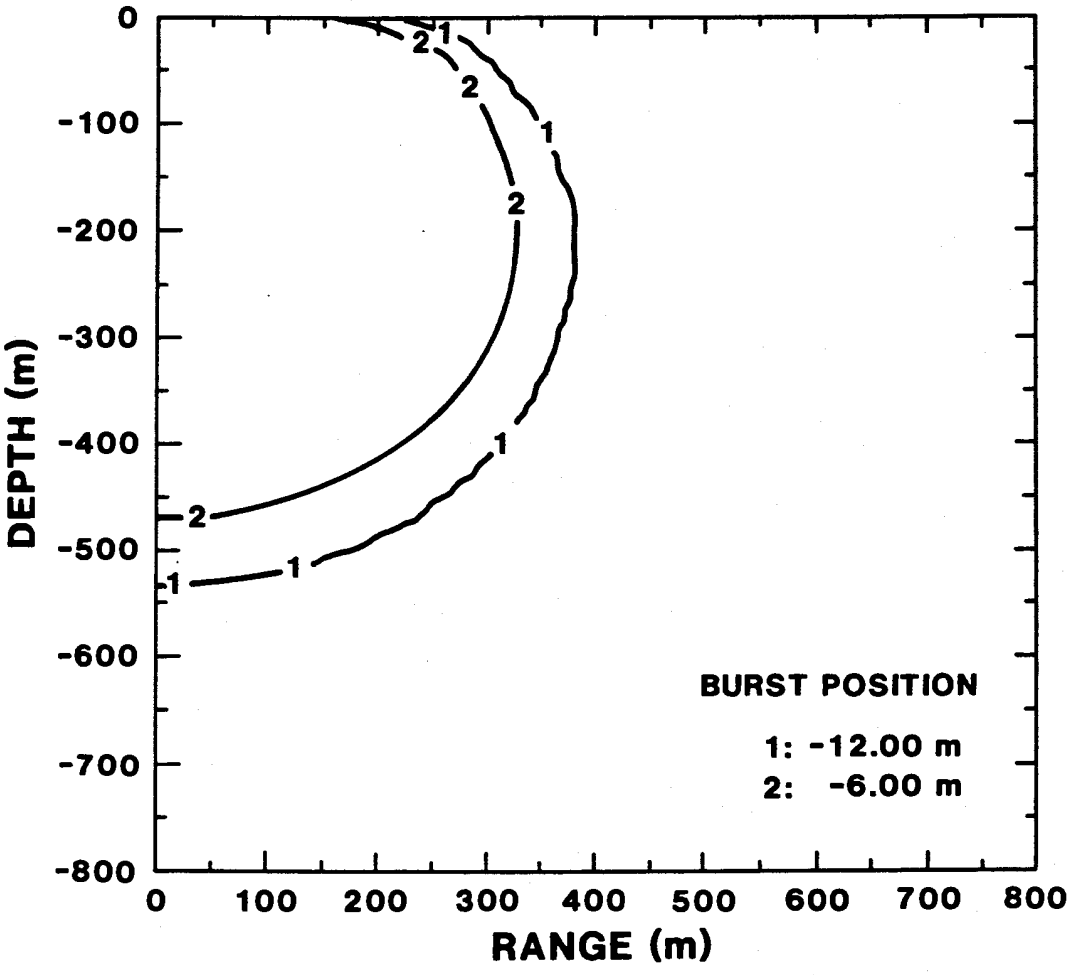


Figure 12: Comparison of 1.0 kb peak axial stress contours for EPW bursts.

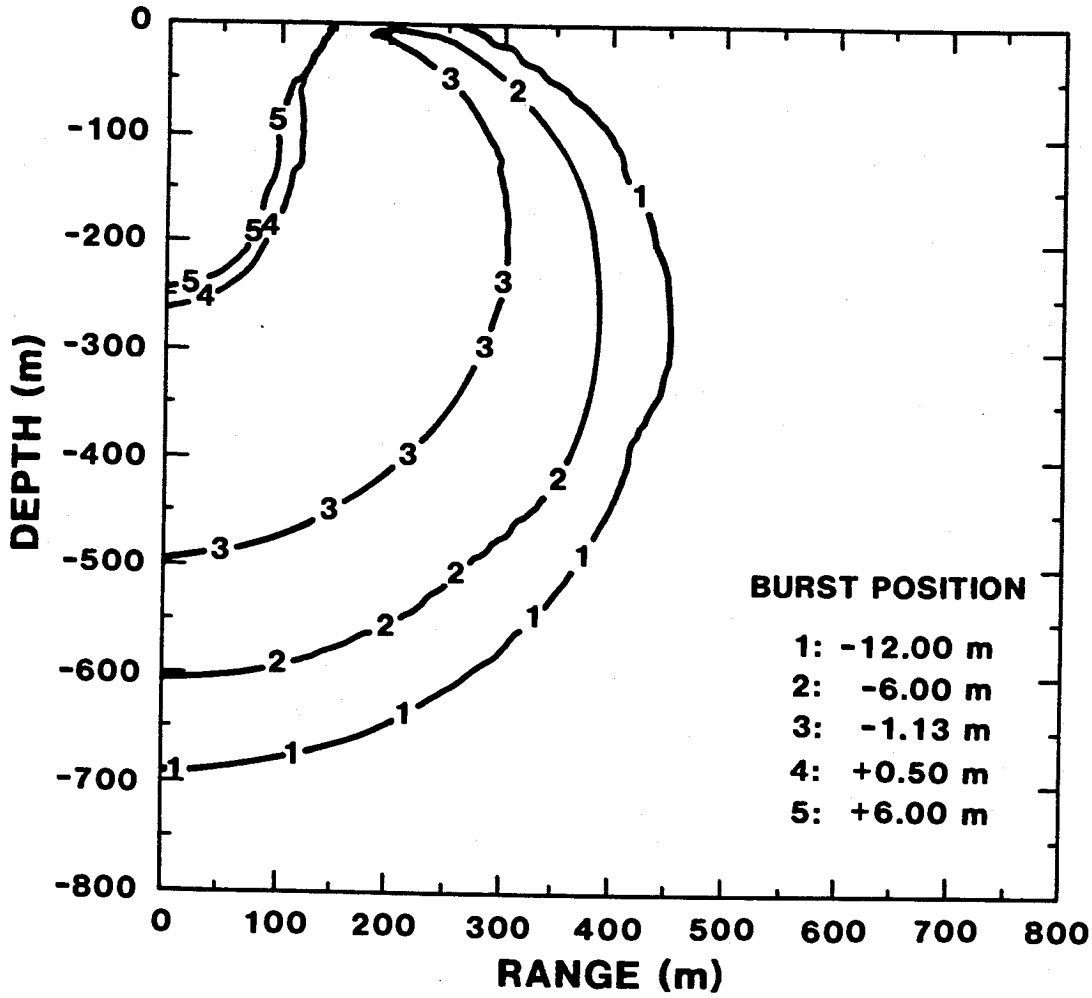


Figure 13: Comparison of 0.5 kb peak axial stress contours for above-surface and EPW bursts.

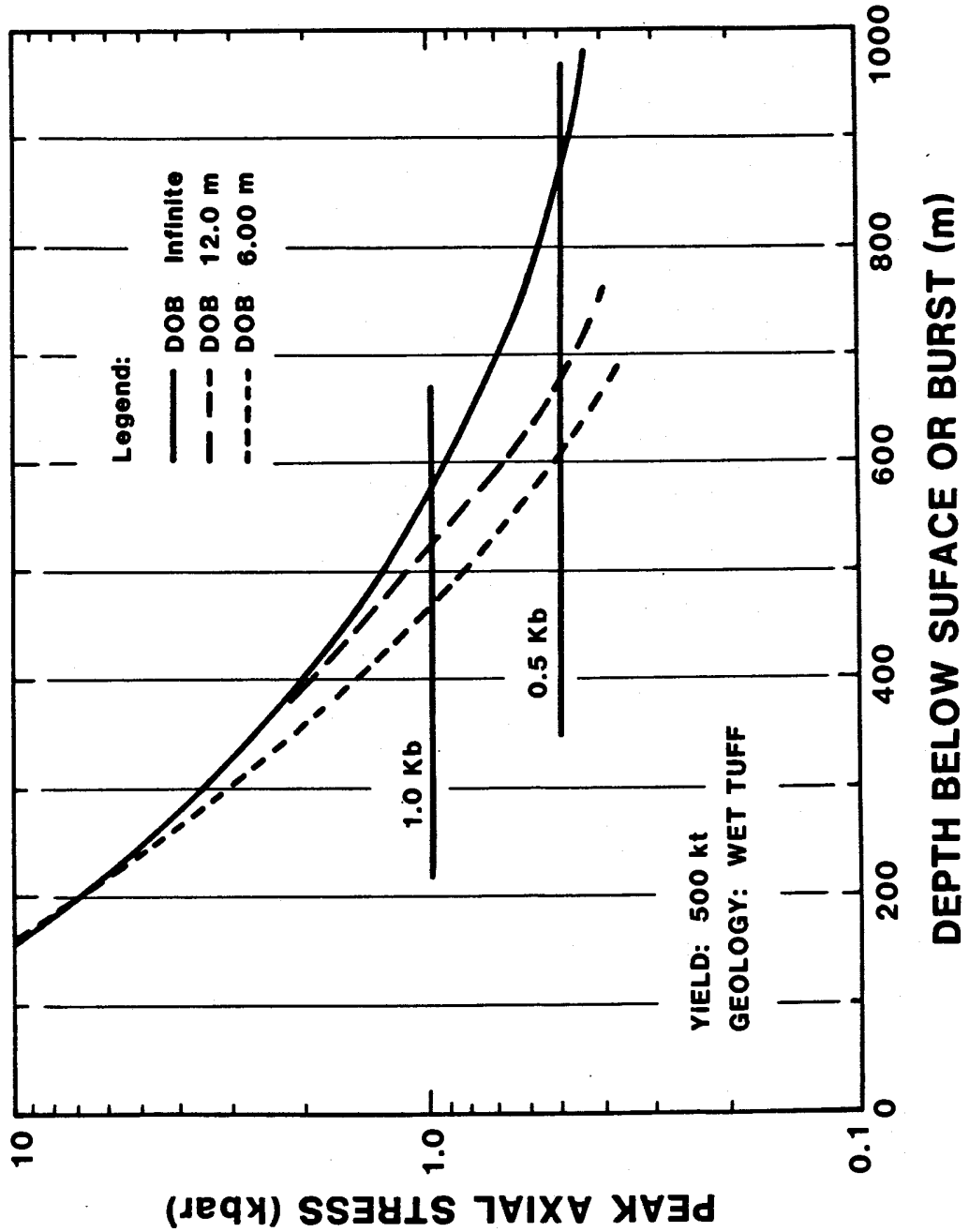


Figure 15: Peak stress on axis versus depth for EPW bursts and fully-contained explosion.

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Tunnel Damage from Ground Shock (U)

Jon Rogers
Dept. 5412

June, 1997

M Buchmeld 10/23/00

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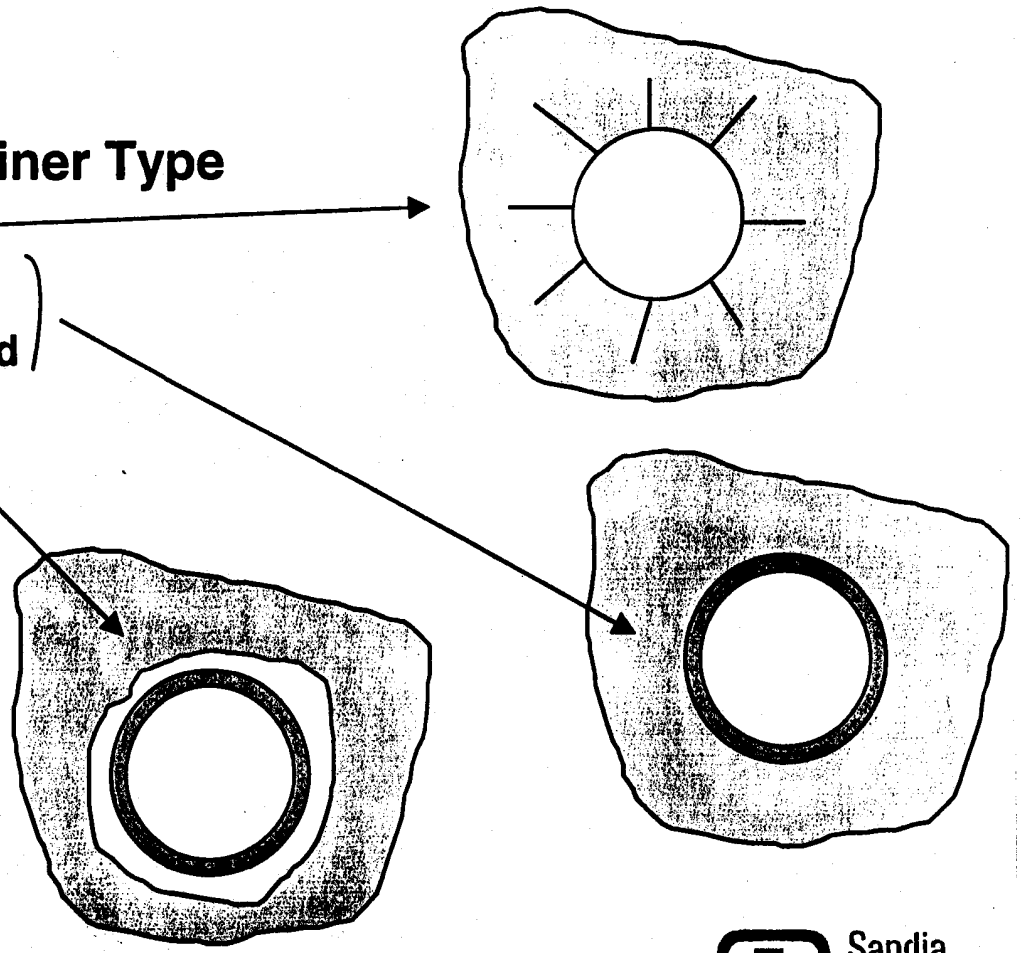
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First Define the Tunnel (U)

- Geology
  - local to the site
- Construction/Liner Type
  - Rockbolted
  - Concrete lined
  - Composite lined
  - Backpacked



"Calibration" of Hendron and Aiyer Results (U)

- "Calibrated" for various construction types
  - Much of data from 3 UGTs
    - Piledriver and Hard Hat - tests in Granite
    - Mighty Epic - test in Tuff
  - Lots of tunnel sections and liner types, few large sections
    - Most sections 6 - 7 feet in diameter
    - Most sections loaded side-on
- Work was in support of Deep Basing (1983)
  - Goal was protection of U.S. assets
  - Focus was on "Sure Safe" design
    - Choose to err on the side of "defender conservative"

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DoD b(1)

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5. Ballistic Missile Threat Specification (U), BMDO, June 1994, Secret.

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By Donald P Dickason / Jim Dominici
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of

LOS ALAMOS SCIENTIFIC LABORATORY

PART II (U)

by

Samuel Glasstone

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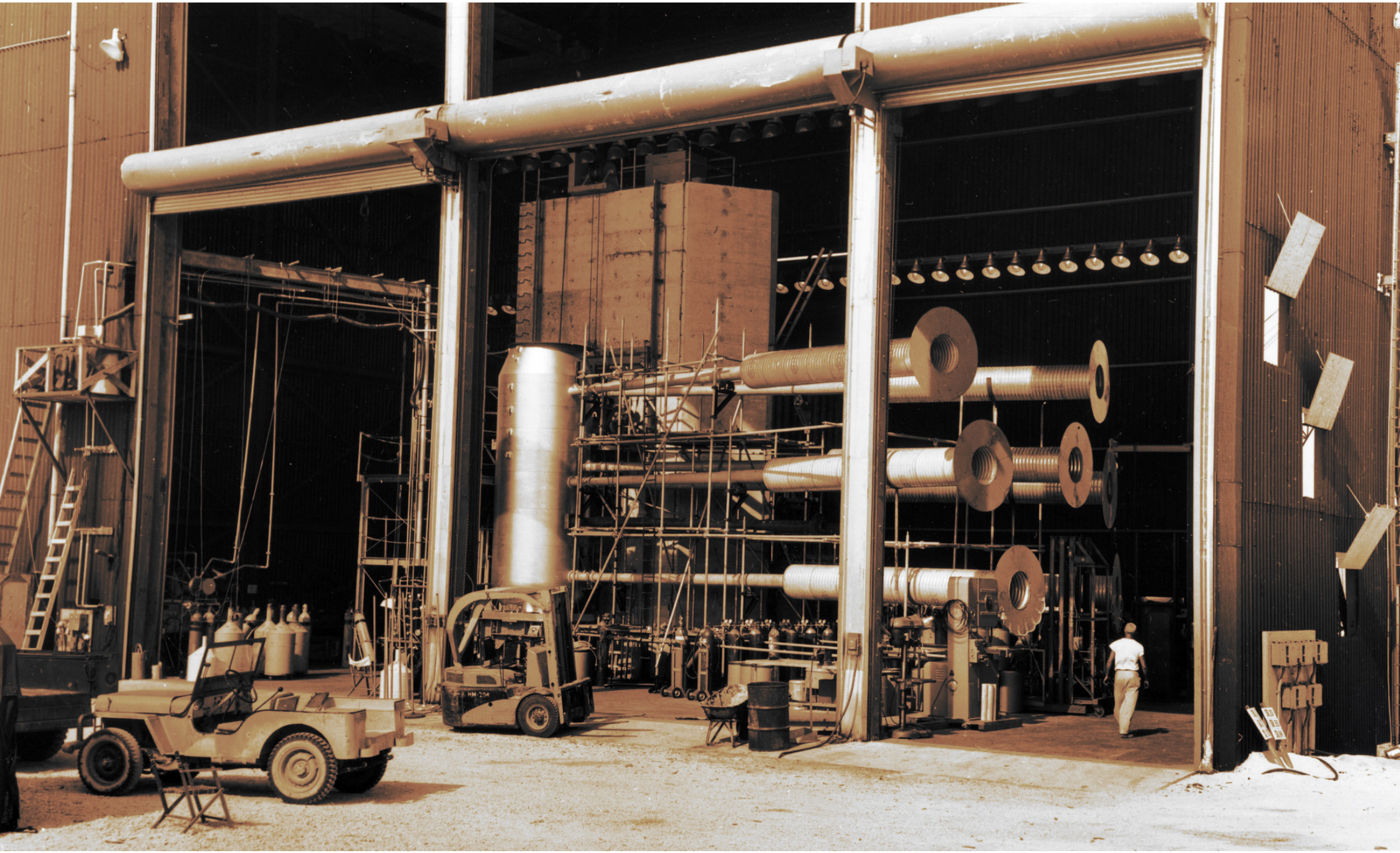
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Section 8.2 Thermonuclear Reaction Rates 5
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10 Mt MIKE H-bomb, 1952



Chapter 8

Thermonuclear Devices

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8.1 Introduction

DOE b(3)

Thermonuclear Burning

As seen in the preceding chapters, thermonuclear (D-D and D-T) reactions are used for the initiation and the boosting of nuclear fission chains.

The problem to be considered in this chapter is the development of methods whereby large amounts of energy may be produced from thermonuclear reactions.

The continuous release of energy in a thermonuclear system involves the propagation of a chain reaction; but this resembles a thermal chain, such as occurs in flame propagation, rather than a fission chain. In the latter, particles, i.e., neutrons, produced in one step of the reaction are the means for causing further (fission) reaction to occur. In a thermonuclear system, as in a flame, the energy liberated in the reaction raises a volume element to a high temperature. This heats an adjacent volume element sufficiently to permit the reaction to occur rapidly. The resulting increase of temperature then heats a further volume element, and so on, until the reaction (or flame) has spread throughout the whole system. It is this similarity between thermonuclear reactions and flame propagation that gives rise to the use of the term "burning" in the former case (see Section 1.6), as in the latter.

It should be noted that whether burning, i.e., propagation of the reactions, will occur or not, depends on a competition between the rate at which heat is produced by the reactions and that at which it is lost, from a given volume element, in various ways. The former must, of course, predominate if burning is to occur, and the temperature attained must be high enough for the reactions to be rapid.

Material and Radiation Energies

At temperatures of the order of a few thousand degrees, the energy of a system is almost entirely material energy, i.e., essentially thermal kinetic energy with perhaps a small amount of potential energy. This material energy, E_m, is proportional, approximately, to the mass, M, of the system and to its absolute temperature, T; thus,

DOE b(3)

$$E_m = aMT \,, \qquad (8.1)$$

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where a may, for the present purpose, be regarded as constant for the given system.

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$$D^2 + D^2 \rightleftharpoons \begin{cases} He^3 + n^1 + 3.27 \text{ Mev} \\ T^3 + H^1 + 4.04 \text{ Mev} \end{cases}$$

$$D^2 + T^3 \longrightarrow He^4 + n^1 + 17.6 \text{ Mev}.$$

It is seen that there are two alternative D-D reactions; they take place roughly at the same rates, so that each may be regarded as occurring in half the D-D interactions.

D-D and D-T Cross Sections

The rate of a nuclear process is usually expressed in terms of the effective area per nucleus, i.e., the cross section. These cross sections can be determined experimentally by accelerating deuterons or tritons to known energies and determining the extent of interaction with other (stationary) nuclei. The results obtained for the second of the D-D reactions given above, represented by DD_p, and for the D-T reaction are shown in Fig. 8.2. The values for the other D-D reaction are very similar. The cross sections, $\sigma(E)$, are expressed in barns, i.e., in units of 10^{-24} cm^2, as a function of the deuteron energy in kev.

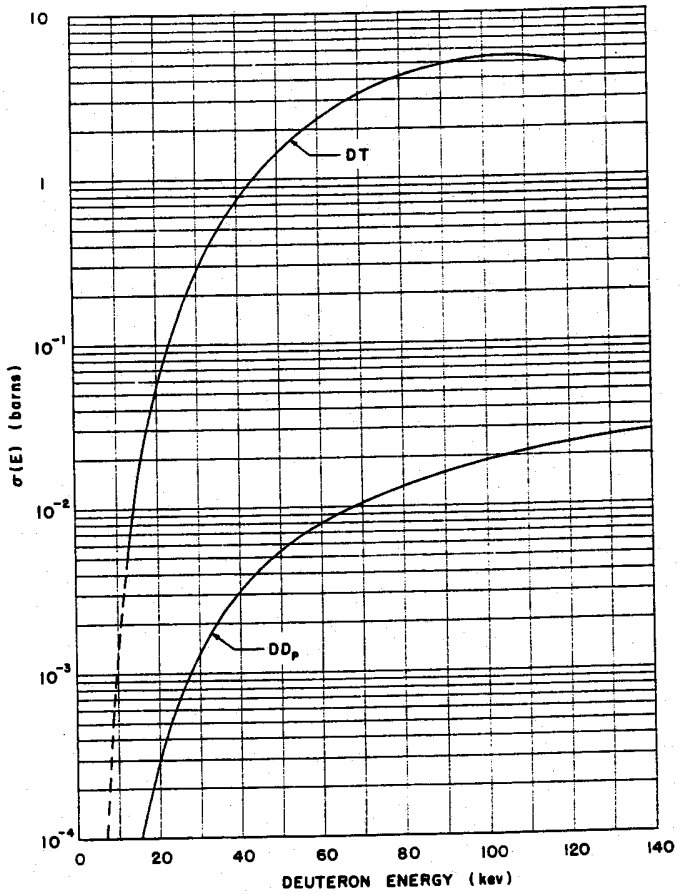


Fig. 8.2

The cross section, or reaction rate, is seen to increase with the energy, due to the increased probability of penetration of the potential barrier. It may be mentioned that the cross-section curve for the D-T reaction is not only somewhat higher than expected, but it also exhibits a maximum at energies around 100 kev (see Fig. 8.2). This is attributed to the phenomenon of resonance.

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Calculation of Reaction Rates

Consider a quantity of deuterium, and let the cross section, σ, represent the effective area of a nucleus of a given energy for the D-D reaction. If v is the velocity of the deuterium nucleus, then it will sweep out an effective volume σv in unit time, e.g., per sec. If there are N deuterons per cm^3, then the total effective volume swept out is σvN per cm^3 per sec. Since there are N deuterons present per cm^3, the number of effective D-D collisions, i.e., the rate of the D-D reaction, is equal to $\sigma vN^2/2$ per cm^3 per sec. The factor of one half is introduced here, for otherwise each D-D collision is counted twice. In the case of the D-T reaction, the corresponding rate would be σvN_dN_t per cm^3 per sec, where N_d and N_t are the numbers of deuterons and tritons, respectively, per unit volume.

It is seen from the foregoing argument that, apart from the density of the material, i.e., the number of nuclei per cm^3, the rate of a nuclear reaction is determined by the product σv. In a system at a given temperature, T, not all the nuclei will have the same energy and, hence, velocity.* The energies will, in fact, be distributed over a large range from very small to very large, as indicated qualitatively, in Fig. 8.3; n(E)/n is the fraction of nuclei having energy E, per unit energy interval. If the energy distribution follows the Maxwell law, then the energy corresponding to the most probable velocity, per unit velocity interval, is equal to kT, where k is Boltzmann's constant; this is generally referred to as the energy corresponding to the temperature T.

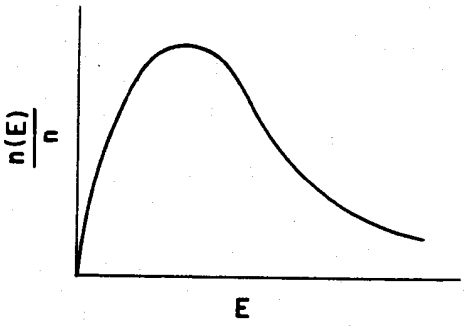


Fig. 8.3

As implied earlier, it has become the practice in the thermonuclear field to state the temperature as the energy kT, usually expressed in kev. Since k is 8.62×10^{-8} kev per degree, it follows that

$$\text{Temperature in kev} = 8.62 \times 10^{-8}\ T\ ,$$

where T is the absolute (Kelvin) temperature. Thus, a so-called temperature of 1 kev would correspond to a Kelvin temperature of 1.16×10^7 degrees.

*Since the energy E is kinetic, it is equal to $1/2\ mv^2$, where m is the mass of the nucleus; hence, v is determined by E, for a given species.

In order to determine the rate of a nuclear reaction at a given temperature, it is necessary to obtain a proper weighted average of σv, i.e., $\overline{\sigma v}$, over the whole energy range, since both σ and v vary with the nuclear energy. This can best be done by taking the experimental values of σ as a function of E (or of v), from Fig. 8.2, multiplying by the corresponding velocity, v, and then weighting each product according to the Maxwellian probability of that velocity. This operation may be expressed analytically by

$$\overline{\sigma v} = \frac{\int [\sigma(v)v]\ v^2 e^{-\frac{mv^2}{2kT}}\ dv}{\int v^2 e^{-\frac{mv^2}{2kT}}\ dv}, \qquad (8.5)$$

where the integrand in the denominator is the Maxwell factor. The values of $\overline{\sigma v}$ for one of the D-D reactions and for the D-T reaction, obtained somewhat in this manner, are plotted in Fig. 8.4 as a function of the temperature in kev. It is seen that, under equivalent density conditions, the D-T reaction is of the order of 50 to 100 times as fast as each of the D-D reactions at the same temperatures, at least in the range from 1 to 100 kev.

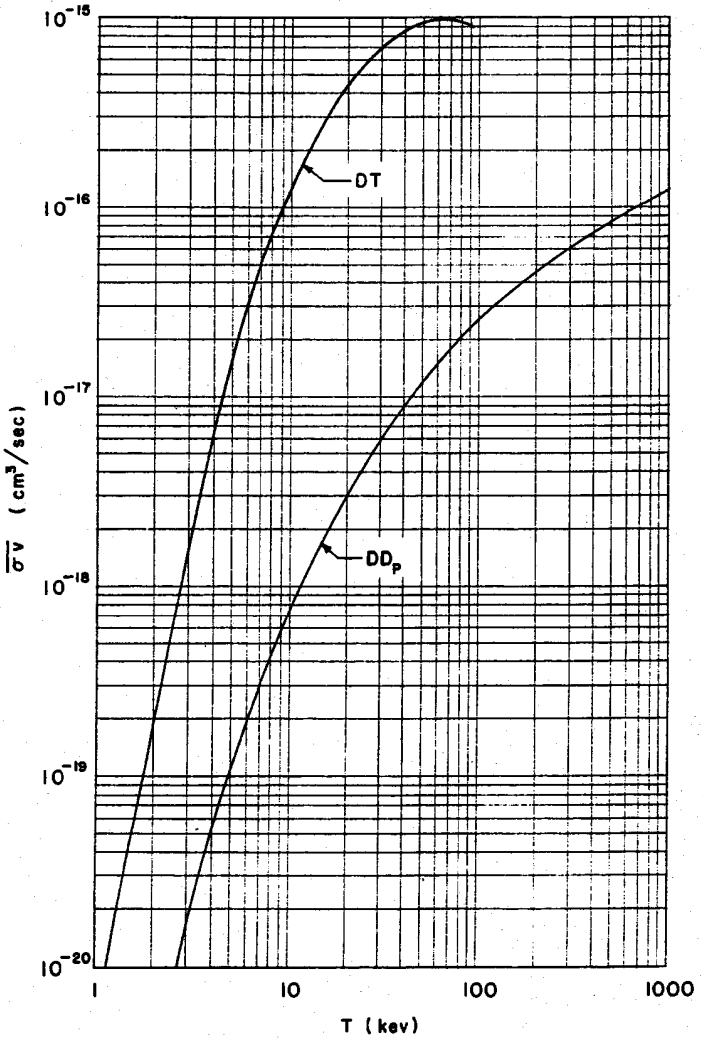


Fig. 8.4

The Reproduction Time

To illustrate the use of the data in Fig. 8.4, the energy reproduction time, i.e., the time required for the energy to double itself, in deuterium will be calculated. In every effective D-D collision, two deuterons are consumed, but in (roughly) half of these reactions a tritium nucleus is produced, which rapidly undergoes the D-T interaction with another deuterium nucleus. Thus, on the average, 2.5 deuterons are used up in every

effective collision.* From the arguments presented above, the number of effective D-D collisions is $\overline{\sigma v} N^2/2$ per cm^3 per sec, and so deuterons are consumed at the rate of $2.5\ \overline{\sigma v} N^2/2$ per cm^3 per sec. Since N is the number of deuterons present per cm^3, the fraction, F_t, of the deuterium reacting in time t sec is given by

$$F_t = \frac{2.5}{N}\ \overline{\sigma v}\ \frac{N^2}{2}\ t = 1.25\ \overline{\sigma v} N t\ , \qquad (8.6)$$

where t is assumed to be so short that N does not decrease appreciably.

If the two D-D reactions take place to, approximately, the same extent and every tritium nucleus formed rapidly undergoes the D-T reaction with another deuteron, the total energy liberated will be 4.04 + 3.27 + 17.6 = 24.9 Mev or, roughly, 25 Mev, for the consumption of five deuterons, i.e., 5 Mev or 5000 kev per deuteron. The energy ΔE produced in time t, per deuteron present in the system, is equal to F_t x 5000 kev, and so

$$\Delta E = 6250\ \overline{\sigma v} N t \text{ kev per deuteron.}$$

If E_{tot} is the total energy per deuteron present in the system, then the reproduction time, t_{rep}, i.e., the time required for the energy to double itself, due to the D-D and D-T reactions, is given by

$$t_{rep} = \frac{E_{tot}}{6250\ \overline{\sigma v} N}\ . \qquad (8.7)$$

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DOE 5(3)

Production of Lithium-6

The enrichment of lithium-6, from its normal isotopic proportion of 7.3 per cent to the 95 per cent or so desirable for thermonuclear devices, is carried out by a chemical, isotopic exchange process. Lithium amalgam, consisting of a solution of metallic lithium in mercury, is allowed to interact with an aqueous solution of lithium hydroxide in water. As a result of the exchange between the lithium isotopes in the mercury and those present as ions in the water, the ratio of lithium-6 to lithium-7, at equilibrium, is larger in the amalgam than in the aqueous solution. The separation coefficient is not much greater than unity, and appreciable enrichment is achieved by a continuous counter-current process. The lithium amalgam, flowing in one direction, becomes steadily richer in the Li^6 isotope, whereas the proportion of lithium-7 increases in the hydroxide solution. Because of the separation difficulties, highly enriched lithium-6 is still rare and costly.

8.6 Thermonuclear Tests

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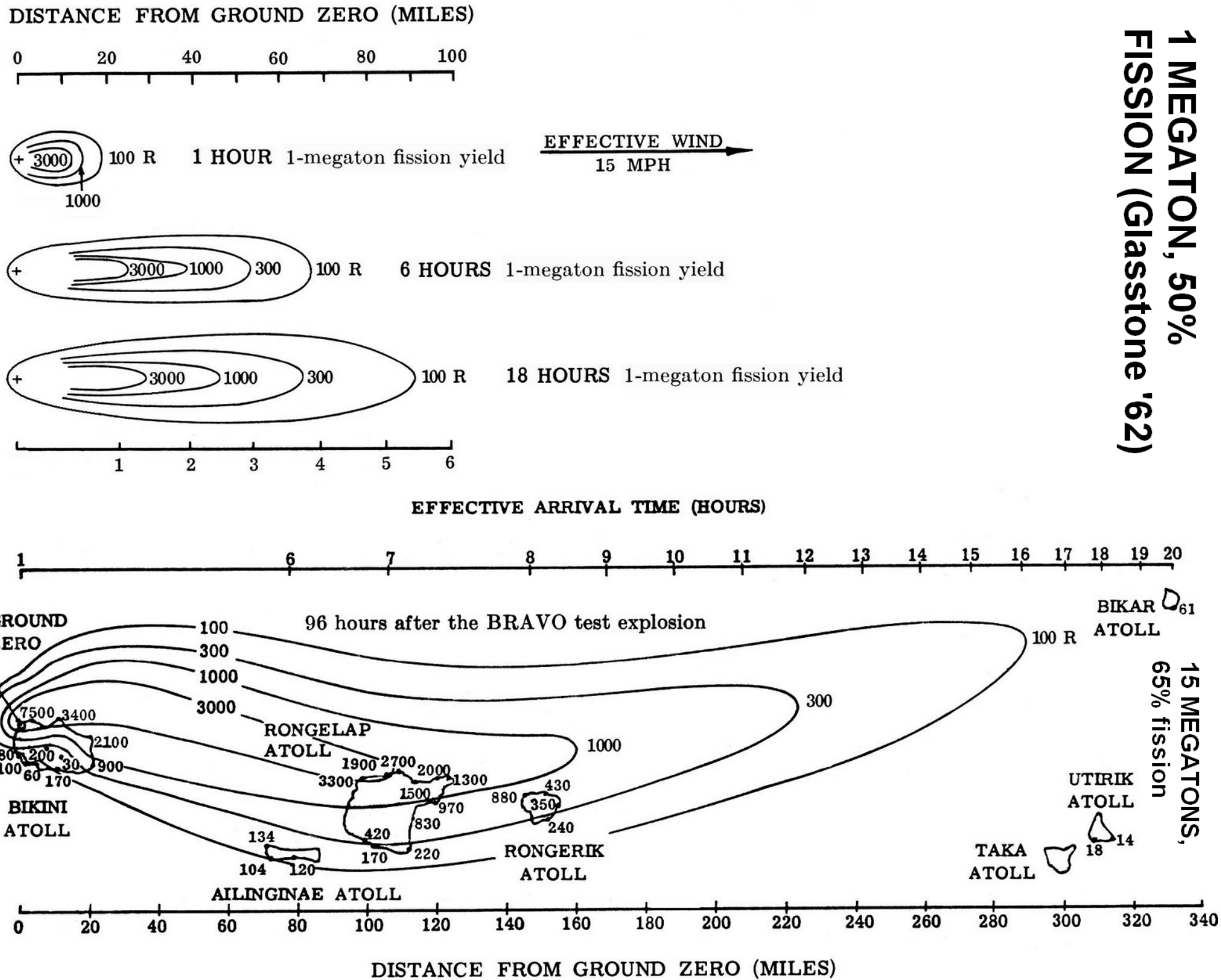

1.09 Mt Arkansas 1533 m altitude


1.09 Mt Arkansas 1533 m altitude

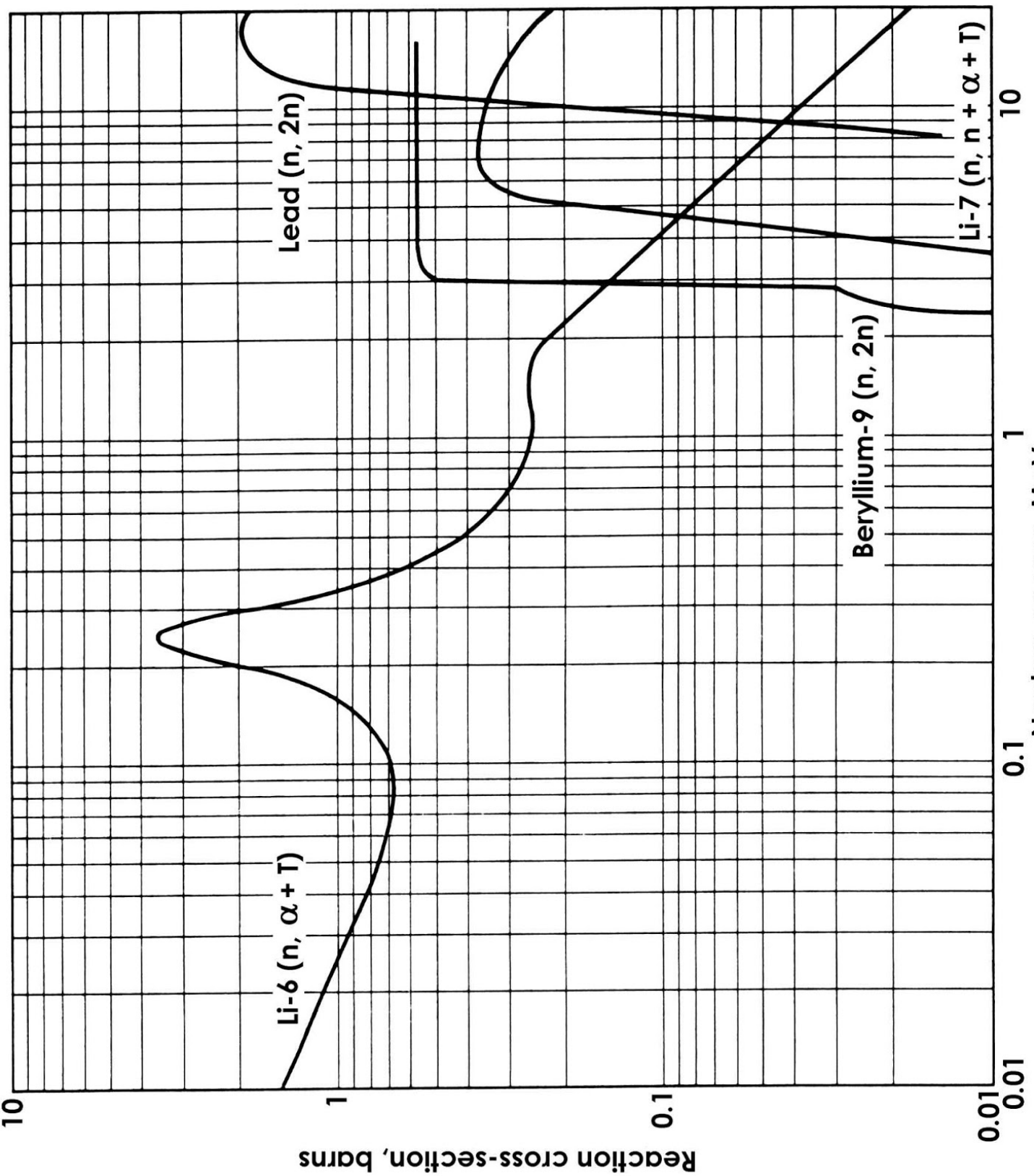

300 kt Grapple-1, 2,200 m altitude



3 MT at 2,350 m HOB. Grapple Y, 28 April 1958.


1 MEGATON, 50% FISSION (Glasstone '62)
DISTANCE FROM GROUND ZERO (MILES)
0 20 40 60 80 100
+ 3000 100 R 1 HOUR 1-megaton fission yield
1000
EFFECTIVE WIND
15 MPH
+ 3000 1000 300 100 R 6 HOURS 1-megaton fission yield
+ 3000 1000 300 100 R 18 HOURS 1-megaton fission yield
1 2 3 4 5 6
EFFECTIVE ARRIVAL TIME (HOURS)
1 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
96 hours after the BRAVO test explosion
15 MEGATONS, 65% fission
GROUND ZERO
100
300
1000
3000
100 R
300
1000
7500 3400
2100
80 200 30
100 60 170
900
BIKINI ATOLL
RONGELAP ATOLL
1900 2700 2000
3300
1300
1500
970
880 430
350
240
830
420
134
104 120
170 220
RONGERIK ATOLL
AILINGINAE ATOLL
BIKAR ATOLL 61
UTIRIK ATOLL
14
TAKA ATOLL
18
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340
DISTANCE FROM GROUND ZERO (MILES)

Based on data published in U.K. National Physical Laboratory, Kaye and Laby science data book, 1995 edition:



CLEAN H-BOMB FUSION CHARGE PUSHER

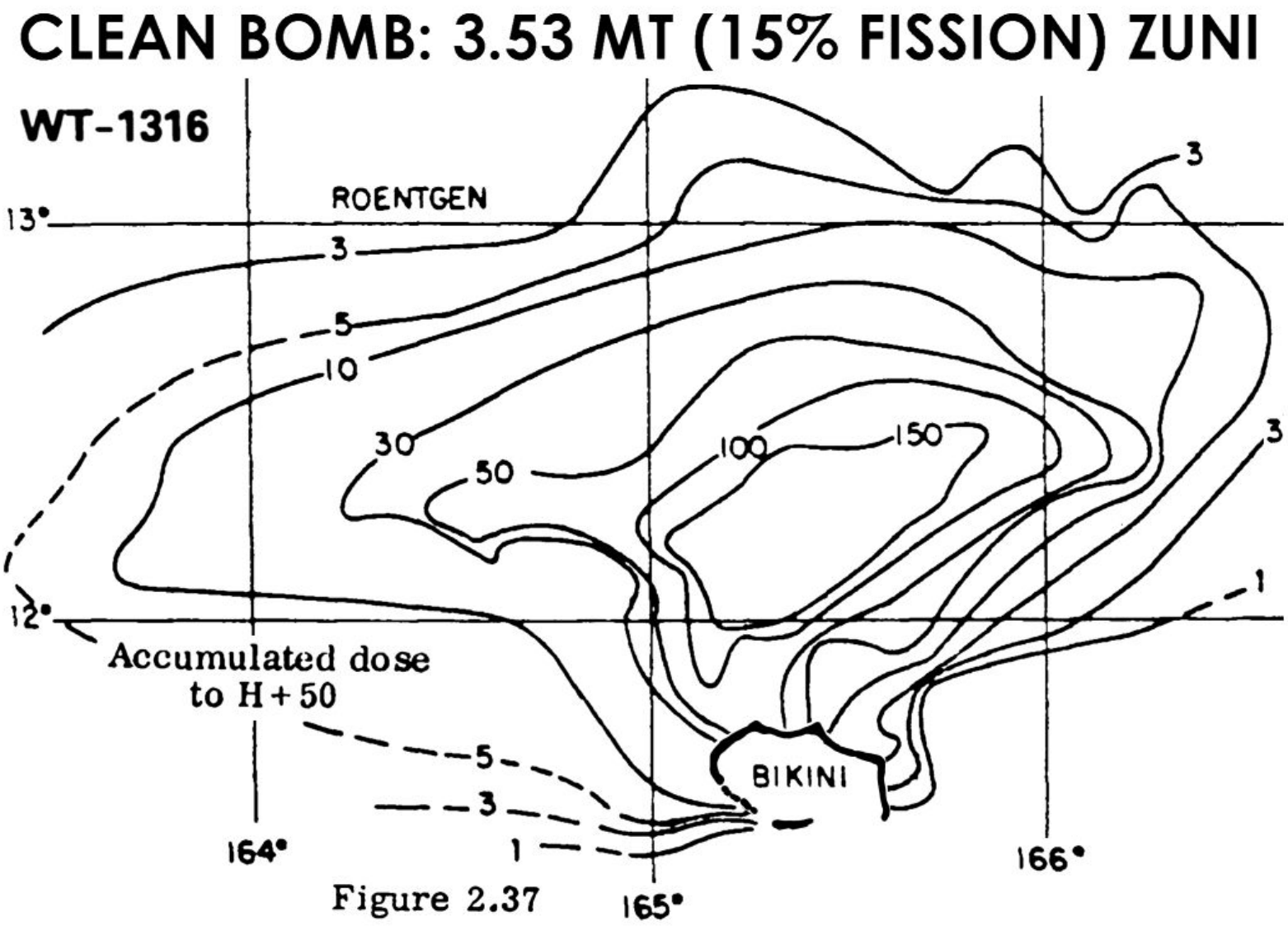


Figure 2.37

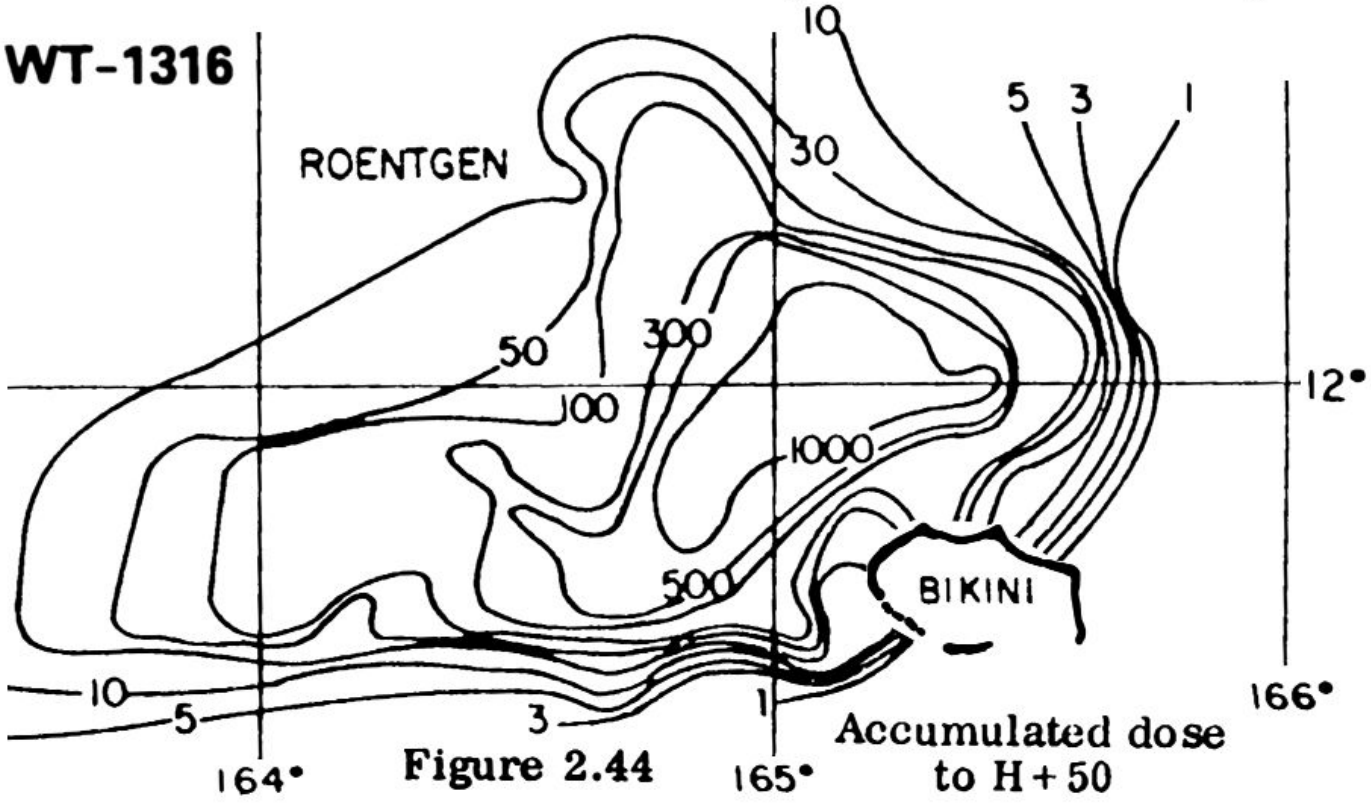


Figure 2.44

Doses given here have been corrected in WT-1316 for a land terrain. Note that doses scaled with the fission yield.

Clean H-Bomb Test Junked As U.S. Fears Mammoth Propaganda Dud

WASHINGTON (UPI) — The United States called off its planned show-the-world test of a "clean" H-bomb because the explosion was shaping up as a propaganda dud, informed sources said Wednesday.

There was even a possibility, according to government authorities, that the public shot could have backfired spectacularly against the United States in world public opinion.

The State Department announced cancellation of the test Saturday. The explanation given was that the earliest possible date for the shot had been pushed back by poor weather to late August. The department said that would interfere with attendance at the Geneva, Switzerland, conference on peaceful atomic energy starting Sept. 1.

Fourteen nations had been invited to witness the test. It was billed as a demonstration of a U.S. nuclear weapon of large destructive power—in the range of a million tons of TNT—with little radioactive fallout measured in elements believed dangerous to mankind.

Russia and Communist Czechoslovakia declined to attend. Only a handful of acceptances were received.

"Nobody was really interested in the test and the whole thing promised to be a dud," one source told United Press International. That appraisal was confirmed in informed quarters. One congressional informant said "hardly anybody" wanted to attend the demonstration shot.

Several sources suggested an added reason for the cancellation. This was rooted in the controversy over whether the radioisotope carbon-14, created by all nuclear blasts, is as dangerous as strontium-90 and other well-recognized fallout hazards.

Coast Guard Asks Position Of Raft

LONG BEACH, CALIF. (UPI) —The Coast Guard broadcast an appeal Tuesday for ships to report the position of the raft Lehi IV if it is spotted on its drifting trip to Hawaii.

The request was made more than two weeks after the raft was towed to sea from nearby Redondo Beach by the fishing boat "Redeemer of Israel."

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LOS ALAMOS SCIENTIFIC LABORATORY
of the
UNIVERSITY OF CALIFORNIA

Report written:
January 1954

LA-1632

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WEAPONS ACTIVITIES
of
LOS ALAMOS SCIENTIFIC LABORATORY
PART I (U)

by
Samuel Glasstone

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ACKNOWLEDGEMENT

The preparation of this report has required the coverage of both considerable range and depth of technical detail. The work could not have been completed, especially in the time available, without the generous cooperation of many members of the Laboratory staff. It is impossible to mention the names of all who contributed in one way or another, but their invaluable help is gratefully acknowledged.

In the course of collecting material, I have been greatly impressed by the excellent morale and enthusiasm that prevail throughout the Laboratory. The general scientific atmosphere is undoubtedly responsible for the important progress in weapons development summarized here. In addition, it has made the preparation of this report a pleasure and a privilege.

Samuel Glasstone

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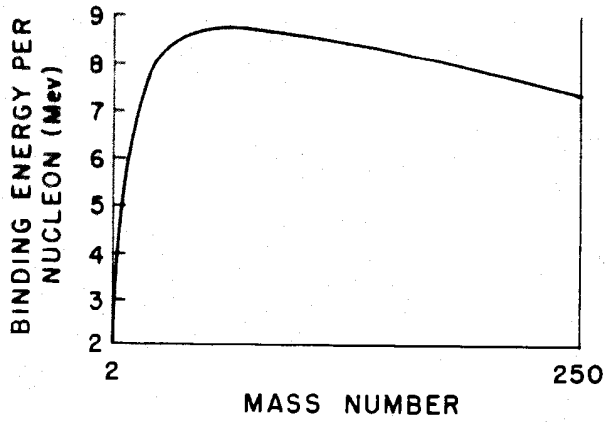


Fig. 1.1

A useful quantity is the mean binding energy per nucleon, i.e., B.E./A, where the mass number, A, is the number of protons and neutrons in the nucleus. The values of B.E./A for many nuclear species have been determined, from their known masses, and when plotted against the respective mass numbers, as in Fig. 1.1, the results are found to fall on, or very close to, a continuous curve. The significant aspect of this curve, for the present purpose, is that the mean binding energy per nucleon is less for the lightest and for the heaviest nuclei than it is for those of intermediate mass. It is this fact which accounts for the liberation of energy accompanying either the fission of heavy nuclei or the fusion of light nuclei, as can be shown in the following manner.

Calculation of Fission Energy

Uranium-235 undergoes fission in some thirty or more different ways, i.e., many different pairs of nuclei are formed. In the great majority of cases, however, the mass numbers of the fission products lie within the range from about 80 to 150, and from Fig. 1.1 it is seen that the average value of the binding energy per nucleon in this region is about 8.4 Mev. On the other hand, in the original uranium-235, the binding energy per nucleon is 7.5 Mev. Hence, the total energy which would be required to break up a uranium-235 nucleus into its 235 constituent nucleons would be 235 x 7.5 Mev, whereas for the fission product nuclei the corresponding energy would be about 235 x 8.4 Mev. In this calculation the neutrons involved in fission are neglected for simplicity, since they will have little effect on the final result. Consequently,

$$\text{Uranium-235} + (235 \times 7.5)\text{Mev} \longrightarrow 235 \text{ nucleons}$$
$$\text{Fission products} + (235 \times 8.4)\text{Mev} \longrightarrow 235 \text{ nucleons}$$

and upon subtraction and rearrangement it is seen that

$$\text{Uranium-235} \longrightarrow \text{Fission products} + (235 \times 0.9)\text{Mev}.$$

In other words, the fission of uranium-235 is accompanied by the release of 235 x 0.9 Mev, i.e., about 200 Mev, of energy.

For a specified shape and composition, the size of a critical system can be decreased by surrounding it with a material which scatters neutrons back into the fissile core. By reducing the number of neutrons that escape, a smaller size (or mass) can become critical. Such a scattering material, on account of its function, is referred to, in general, as a reflector. In nuclear weapons it is called a tamper, because, in addition to decreasing the loss of neutrons by escape, it delays expansion of the exploding mass and permits a higher yield from the system undergoing fission, as will be seen later.

As is to be expected, increasing the thickness of the tamper decreases the escape of neutrons and thus makes possible a smaller critical mass of the fissile (or core) material. However, it has been shown by theoretical calculations, and verified experimentally, that when the tamper thickness reaches a certain value there is little more to be gained by a further increase of thickness (Fig. 1.2). Thus, when the thickness is about two to three neutron mean free paths in the given tamper material, its effectiveness in reducing neutron losses is within 10 per cent or so of an infinitely thick tamper.

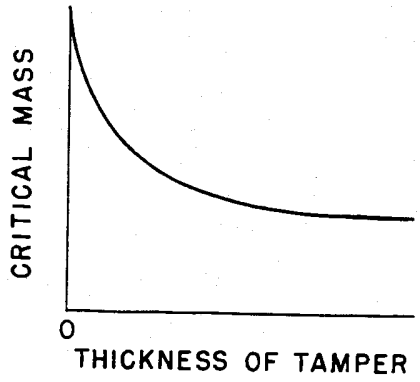


Fig. 1.2

Under precisely specified conditions, and for a given fissile (core) material, there is a definite mass that will be just critical. This is called a "crit." The critical masses of spheres of uranium-235 (94 per cent purity) and of plutonium-239 (97 per cent purity) are given in Table 1.3. In the first column are the values for a bare (untamped) sphere, whereas the values in the second column are for a thick (infinite) tamper of natural uranium metal. The effect of the tamper in reducing the critical mass of the core is very striking.

Table 1.3 Critical Masses of Spheres

Fissile Material	Bare	Tamped
Uranium-235	52 kg	17.2 kg
Plutonium-239	16 kg	5.8 kg

It may be noted that there is still another factor which affects the critical size: it is the speed (or energy) of the neutrons causing fission. The rate of the fission process is determined by the fission cross section, as will be seen later, and this varies with the neutron energy. However, as far as nuclear fission weapons are concerned, it may be tacitly assumed that only fast

neutrons, mainly with energies in the range from 0.5 to 2 Mev, are involved. Because of the relatively long slowing-down time, fission by slow neutrons would be less effective in an explosion.

1.3 Attainment of Criticality

Assembly Method (Gun-Type Weapons)

As long as a mass of fissile material is less than the critical value, i.e., it is subcritical for the existing conditions, there is no danger of a chain reaction occurring. But, if energy is to be released, e.g., in an explosion, the system must become critical and, in fact, highly supercritical, as will be seen shortly. There are two general ways, utilized in weapons, for rapidly converting a subcritical system of fissile material into one that is supercritical.

The first may be referred to as the method of assembly. Two portions of subcritical size are brought together very rapidly, so that the combined mass is supercritical. If a burst of neutrons is then introduced, a divergent fission chain will be initiated and there will be a rapid release of energy within a very short time. This is the principle used in weapons of the gun type: one subcritical portion of fissile material is shot into another subcritical portion, the combination exceeding the critical mass.

Compression Method (Implosion Weapons)

The second method of attaining criticality (or supercriticality) is based on compression of the subcritical fissile material. An approximate quantitative treatment of the relationship between the compression ratio and critical mass may be derived as follows. In accordance with the definition given above, the mean free path of a neutron is the average (crow-flight) distance a neutron travels before it interacts with a nucleus. The proportion of neutrons avoiding interaction, and which can consequently escape from the system, will evidently depend on the ratio of the dimensions, e.g., the radius of a sphere, to the mean free path. It is to be expected, therefore, that for a given fissile (core) material, under specified conditions, the critical radius will be approximately proportional to the neutron mean free path; thus, if R_c is the critical radius and λ_c is the mean free path in the core,

$$R_c \propto \lambda_c. \qquad (1.3)$$

The mean free path of a neutron is obviously inversely related to the probability of its interaction; the greater the probability of interaction, the smaller the distance the neutron will travel before it interacts with a nucleus. The probability of interaction is proportional to the number of fissile nuclei per unit volume, and hence to the density; so that, if ρ_c is the density of the core material,

$$\lambda_c \propto \frac{1}{\rho_c} . \tag{1.4}$$

The density of the material is dependent on the compression; thus, if C is the compression ratio, i.e., the volume before compression to that after,

$$C \propto \rho_c . \tag{1.5}$$

Combination of equations (1.3), (1.4), and (1.5) then leads to the result

$$R_c \propto \frac{1}{C} . \tag{1.6}$$

The critical mass M_c is related to the critical radius and the density of the material by

$$M_c = \frac{4}{3}\pi R_c^3 \rho_c , \tag{1.7}$$

and upon substituting equation (1.6) for R_c and equation (1.5) for ρ_c, it is seen that

$$M_c \propto \frac{1}{C^2} . \tag{1.8}$$

The critical mass of a given fissile material is thus inversely proportional to the square of the compression ratio. By increasing the compression the critical mass is consequently decreased.

It follows, therefore, that if a subcritical mass of fissile material is compressed it may become supercritical. [redacted] In other words, it will be highly supercritical, and the introduction of neutrons will cause a rapidly divergent fission chain to develop.

If the mass of fissile (core) material is tamped, then the result in equation (1.8) is true only if both the tamper and the core are compressed to the same extent. Actually, uniform compression is not attained throughout; it is greater near the center of the bomb, i.e., in the core, than further out, e.g., in the tamper. Even within the core itself there is a compression gradient. In general, therefore, the relationship between the critical mass and the average compression ratios of the core (C_c) and of the tamper (C_t) may be represented by

$$M_c \propto \frac{1}{C_c^{1.2}} \cdot \frac{1}{C_t^{0.8}} , \tag{1.9}$$

so that when C_c and C_t are identical, this reduces to equation (1.8). For most cases of interest in the weapons field, a good approximation is

$$M_c \propto \frac{1}{C_c^{1.7}} , \tag{1.10}$$

since the conditions are such that the tamper is compressed to a smaller extent than is the core.

The use of compression to attain supercriticality is employed in weapons of the implosion type; the reason for this name will be seen later. Not only does increased compression result in a decrease in critical mass, it is also accompanied by an increase in efficiency of the energy release, as will be seen in Section 2.1. Consequently, the attainment of higher and higher compressions is one of the important objectives of weapon development.

1.4 Neutron Multiplication

Rate of Fission Reaction

No matter how it originates, an explosion involves the very rapid liberation of a large amount of energy. If the energy is to be produced by fission, then the necessary condition is a very high neutron density, since the rate of fission, and, hence, the rate of energy release, is proportional to the number of neutrons per unit volume. It is of interest, therefore, to investigate the circumstances which lead to a high neutron density.

It was seen earlier that the number of neutrons available to cause fission, for every neutron captured in a fission process, in each generation is equal to k, i.e., to $\nu - \ell$, where ν is the average number of neutrons produced per fission and ℓ is the average number lost by escape and nonfission capture. This means that for every n neutrons present at the beginning of a generation, there will be nk present at the end, so that the gain of neutrons is n(k - 1) per generation. The rate of gain, dn/dt, may then be obtained, roughly, upon dividing the actual gain by the average time, τ, between successive fission generations; hence,

$$\frac{dn}{dt} = \frac{n(k-1)}{\tau} . \tag{1.11}$$

This result will be strictly correct only if the delayed neutrons play no significant part in maintaining the fission chain. As seen above, this condition is applicable to nuclear fission weapons.

The quantity k - 1, which is the excess number of available neutrons per fission, may be

1.5 Production of Weapon Materials

Uranium-235

The two important fissile materials, namely, uranium-235 and plutonium-239, are both produced from natural uranium but by entirely different procedures. Ordinary uranium contains about 0.7 per cent of uranium-235 to 99.3 per cent of uranium-238, and a trace (0.006 per cent) of uranium-234. The uranium-235 is separated by diffusion (through porous barriers) of the vapor of uranium hexafluoride (UF_6), made from natural uranium. The hexafluoride of the lighter isotope diffuses more rapidly than does that of the heavier species, and by the use of several thousand diffusion stages an enrichment of 93.5 per cent, i.e., a material containing an isotopic proportion of 93.5 per cent of uranium-235, can be obtained. The highly enriched uranium hexafluoride is then converted into the tetrafluoride (UF_4) by heating with hydrogen or methane. The uranium tetrafluoride is reduced to metal by means of calcium plus some iodine to act as a "thermal booster." Reaction between iodine and part of the calcium starts at about 400°C; the heat generated raises the temperature sufficiently for rapid reduction of the tetrafluoride by calcium to take place.

Plutonium-239

The element plutonium occurs in nature as virtually insignificant traces, at best. Consequently, the plutonium-239 used in weapons is obtained artifically by a series of nuclear reactions resulting from the exposure of uranium-238 to slow neutrons in a nuclear reactor or "pile." A nuclear reactor is a device in which a fission chain reaction is taking place in a controlled manner. If a material of low mass number, called a moderator, is present, in addition to fissile material, the fission neutrons will be slowed down, and such a system is, in a sense, a source of slow neutrons.

In a reactor, uranium-238 captures neutrons to form a higher isotope, uranium-239, with the emission of gamma radiation; thus

$$_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239} + \gamma,$$

where the subscripts give the atomic numbers, i.e., number of protons, and the superscripts indicate the mass numbers, i.e., total number of neutrons and protons in each case. The uranium-239 is radioactive, with a half life of 23 min, emitting a beta particle. Representing the latter by $_{-1}\beta^{0}$, since it carries a negative charge and has essentially no mass, the radioactive decay process may be written as

$$_{92}U^{239} \longrightarrow {}_{-1}\beta^{0} + {}_{93}Np^{239},$$

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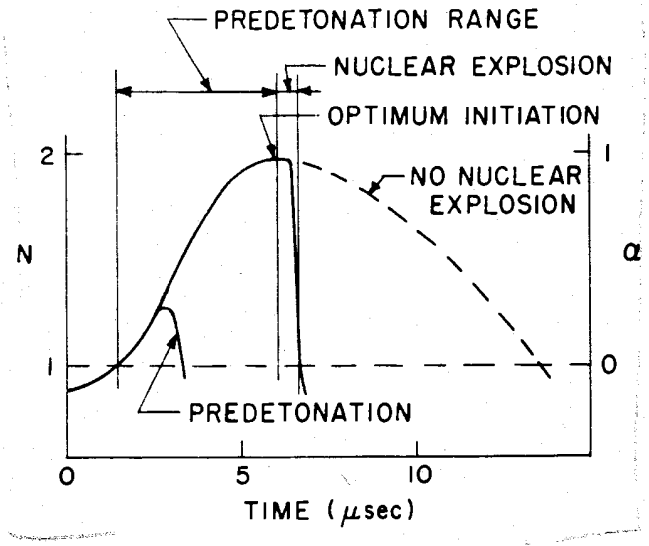


Fig. 2.2

rate, and the abscissae are elapsed time from the beginning of the assembly of a gun-type weapon or compression of an implosion weapon. The numerical values given for N and α are not exact and are intended merely as an indication of the changes which occur. The times, on the other hand, are fairly representative of an implosion weapon. The horizontal dotted line represents the situation for a system that is just critical, i.e., $N = 1$, $\alpha = 0$. Actually, the curves for N and for α as functions of time are somewhat different, and the maxima do not necessarily coincide. However, for the present qualitative discussion, a single curve is adequate.

At zero time the fissile material is subcritical, i.e., $N < 1$, and α is negative, but as compression (or assembly) occurs the value of N increases and α becomes positive, i.e., the system becomes supercritical. If, for some reason, there were no nuclear explosion, the fissile material would suffer decompression, due to its elasticity, after reaching the compression maximum, as indicated by the broken line in Fig. 2.2. In the case of a gun weapon, the parts may fly apart due to the impact.

The optimum yield will obviously be obtained if initiation occurs at the maximum of the curve, i.e., when N has its maximum value. It is at this instant, a few microseconds after compression starts, that the chain should be initiated by the special neutron source. In this event, the whole nuclear explosion will be over in 0.25 to 0.75 μsec, as stated in Section 1.4.

If a neutron entered the core in the period between that at which $N = 1$, $\alpha = 0$ and the maximum of the curve, i.e., while the system is supercritical but before maximum supercriticality is attained, an explosion would occur, but since N would not be as large as is possible, the efficiency will be low. Thus, in order to attain the highest efficiency, predetonation must be avoided. The same will also be true, of course, for postdetonation, i.e., initiation after the maximum of compression has been passed.

The variation of yield with time of initiation may be calculated by any of the methods given above for the determination of efficiency. All that is necessary is to introduce the values of N, α, ρ, etc., which are appropriate to the explosion time in each case. The values

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b(3)

When the shock wave produced by the detonation of the HE inner charge enters the tamper, the latter moves forward, with the attached pusher, through the air space with increasing velocity. As a result, when the tamper reaches the core, it strikes the latter a tremendous, hammer-like blow. More energy is thereby transferred to the core, which is consequently more highly compressed than would be the case in the absence of a free run.

Fig. 3.4

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Composite Cores

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Recovery of Plutonium and Oralloy

Because of their value as fissile materials, all residues of plutonium and oralloy are carefully collected for recovery. Plutonium in the form of metal, e.g., turnings, filings, etc., or of oxide, formed in casting, is dissolved in nitric acid with a little hydrofluoric acid. From the resulting nitrate solution (or slurry), plutonium peroxide is precipitated by hydrogen peroxide and sent to the plutonium production line. Magnesium oxide crucibles and molds and the calcium fluoride-iodide slag remaining from the metal reduction stage are dissolved in nitric acid containing aluminum nitrate. The plutonium is then recovered either by direct extraction in tributylphosphate (TBP) diluted with kerosene, or extraction after an intermediate stage involving volume reduction by precipitation of the plutonium with calcium oxalate as carrier. Organic matter such as clean-up paper, rags, etc., are first incinerated and the residual ash is then treated as just described.

Oralloy turnings and oxide residues are dissolved in nitric acid and after two stages of precipitation with hydrogen peroxide, to insure high purity, the resulting uranium peroxide is converted mainly to U_3O_8 by heat and is then reduced by hydrogen to the dioxide, UO_2. The action of hydrogen fluoride gas converts this to the tetrafluoride and the metal is finally obtained by heating with calcium. Magnesium oxide crucibles, slag, and other residues are treated in a manner similar to that used to recover plutonium. The materials are dissolved in nitric acid with aluminum nitrate and the uranium is extracted by means of TBP in kerosene.

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Fig. 5.9

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Although the efficacy of the Tom initiator has been proven in several test explosions of complete bombs, a detailed study of some of its characteristics has been made.

Fig. 5.10

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*The maximum rate of neutron production is 2.8 neutrons/μsec per curie of polonium, for the (α,n) reaction with beryllium.

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5.5 External Initiators

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One problem in the use of an externally activated initiator is that of precise timing. For this purpose, it is necessary to know the transit time of the bomb, from the triggering of the X-unit to the time the implosion shock wave reaches the center of the core.

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The ENS Initiator

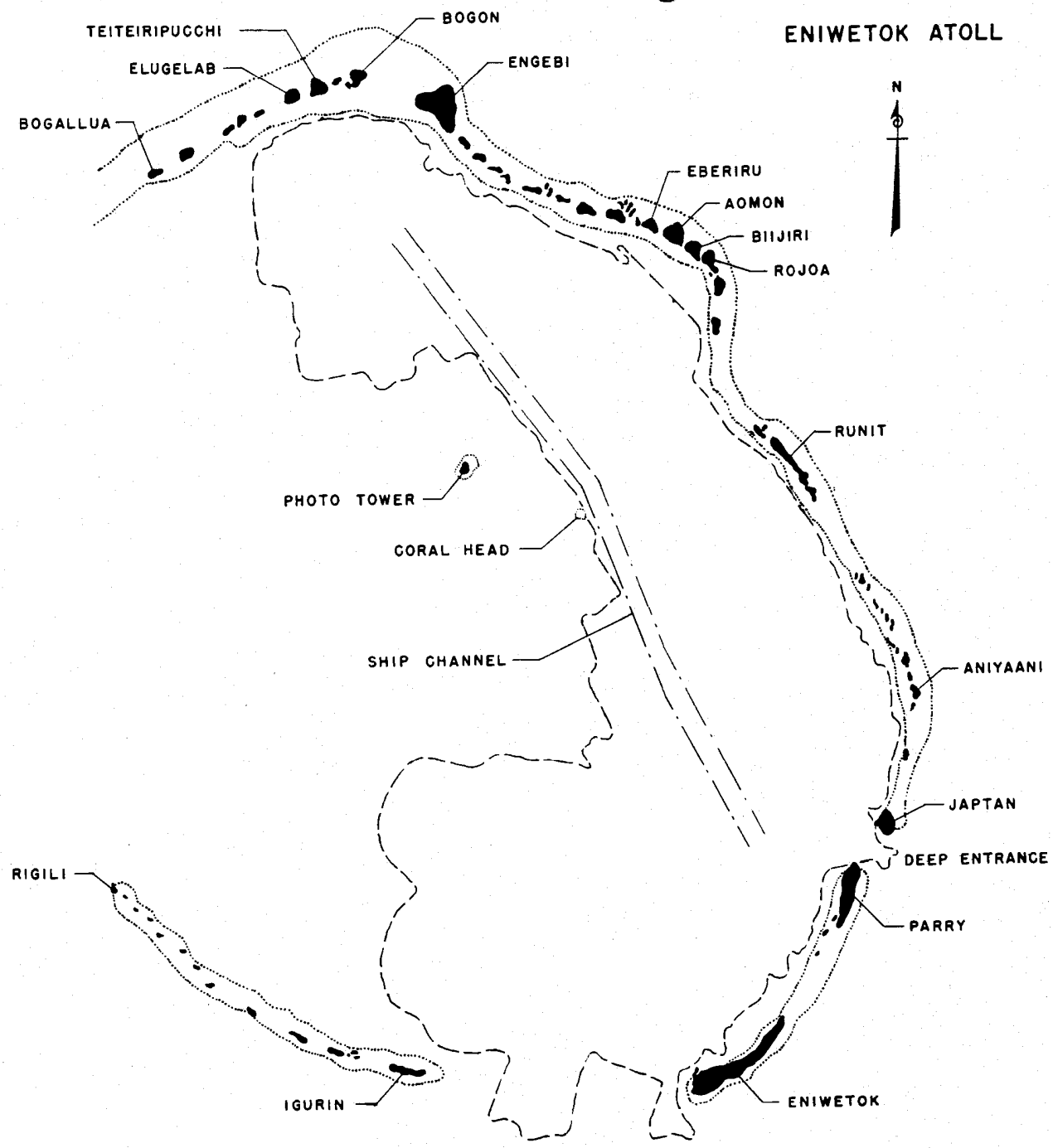
The new external initiator, called the ENS (Experimental Neutron Source), makes use of the fact that 14-Mev neutrons are released in the T-D reaction, between tritium and deuterium nuclei. However, the energy required to make the reaction take place is here supplied by accelerating tritium ions (tritons) in an electrical field; these high-energy ions then impinge upon, and react with, deuterium nuclei.

b(3)

Fig. 5.12

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Fig. 6.2

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Fig. 6.3

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reaching a detecting instrument on the ground will cover a large range of energies. The distribution of the neutrons in this manner is referred to as the neutron spectrum. Those neutrons which have not been scattered have high energies, e.g., 3 Mev or more; others have energies in the intermediate range, while the great majority are slow neutrons. However, because of capture by nitrogen nuclei, very few have energies below about 0.2 ev.

b(3)

The proportion of neutrons produced in fission with energies as high as 14 Mev is very small, but if the D-T reaction is involved, a considerable number of neutrons of this energy will be detected.

6.4 Diagnostic Tests

Determination of Transit Time

A very great variety of measurements are usually made for each test shot, many of which depend upon the particular information required. However, for essentially all fission weapons the so-called standard diagnostic tests are made; these are the determination of the over-all transit time, the multiplication rate (α), and the energy yield of the device. Although yield measurements are always made, determinations of transit time and α are sometimes omitted. Apart from providing useful practical information, the results of the diagnostic tests serve to check theoretical estimates and to supply data upon which further calculations may be based.

For the measurement of the over-all transit time, i.e., from the instant of firing the detonators to the explosion time, two general methods have been used. In the case of a tower shot, a signal is sent over a coaxial cable to a distant cathode ray oscilloscope when the X-unit is fired. The first gamma rays to appear outside the bomb are picked up by a scintillation detector and a second signal is transmitted by cable to the oscilloscope. After making allowance for the difference in lengths of the cables and the time taken for the gamma rays to reach the detector, the transit time of the bomb can be determined from the separation of the two signals.

The procedure described above, which requires cable connections to the X-unit, cannot be used for an airdrop, and in this event the remote method is employed. A radio transmitter, operating at low power, e.g., about 20 watts, is attached to the bomb case. When the X-unit is fired, the output is instantaneously raised to several hundred watts, so that the signal can be detected at a distance and recorded on an oscilloscope. This continues until the intense ionization of the atmosphere, referred to as the "ion curtain," in the vicinity of the bomb, due to the gamma radiation, prevents further propagation of the radio signal. The level at which

this transmission is cut off is not known exactly, but it is believed to be at about the 30th generation, or so. Allowance for this delay is made in estimating the transit time from the duration of the radio signal. If the generation time is relatively long, e.g., for low values of α (Section 1.4), this correction may involve an appreciable error.

Determination of Alpha

Until recently, only one satisfactory method was available for determining the multiplication rate, α; it was based on a measurement of the time-dependence of the prompt gamma rays over a period of about 1 μsec. It can be seen from equation (1.16) that α can be determined if the neutron density, n, in the exploding bomb is known as a function of time. As seen above, the prompt gamma rays are produced, almost entirely, by the action of neutrons within the bomb. Hence, the prompt gamma-ray intensity, fairly close to the bomb, may be taken as being proportional to the neutron density. Consequently, α can be readily calculated from the variation of the prompt gamma rays with time.

Originally large (Rossi-type) ion-chambers, having a fast response, were used to detect the gamma rays, but these have now been replaced by scintillation detectors. The latter are located near the bomb, in the case of a tower shot, and long coaxial cables connect them to the horizontal plates of an oscilloscope. A constant, high-frequency sinusoidal signal applied to the vertical plate supplies a timing record. The oscilloscope trace is photographed and then analyzed to give the time dependence of the prompt gamma-ray intensity. By the use of additional cable, the gamma-ray signal is delayed, so that an intensifier pulse to the oscilloscope can build up and thus permit the trace to be photographed.

In order to cover the large range of intensity, several scintillation detectors may be placed at various distances from the bomb. A common timing system is sometimes used for all the oscilloscopes to which they are connected. The detectors nearest to the explosion record the lower intensities of gamma radiation, whereas those which are more remote indicate the higher intensities. Proper allowance is made, of course, for the attenuation with distance.

For an airdrop the scintillation detectors cannot be placed near the bomb. Consequently, they are located on the ground at known distances from the assumed detonation point. Because of the absorption of the radiation, the intensities at the detectors are relatively small and for high bursts amplifiers may have to be used.

b(3)

Another procedure for obtaining α, which avoids destruction of the detectors, etc., and can be used either for tower shots or airdrops, was first tried out at Operation Sandstone, but did not reach a satisfactory state of development until the Upshot-Knothole test in 1953. One

of its great advantages is that measurements can be made at a distance of 10 miles or so, where the instruments are under direct control, and no coaxial cables are necessary.

When the prompt gamma rays are degraded in energy and absorbed by the air around the bomb, they produce a luminosity, called the Teller light. The intensity of this light is proportional to that of the prompt gamma rays and, consequently, to the neutron density.

b(3)

It is essential that the only light measured should be that coming directly from the bomb to the observer.

In one arrangement for recording the luminosity at very low levels, without the necessity of amplification of signals, the Teller light from the bomb is reflected by a mirror system (Fig. 6.5) and falls on the photomultiplier tube. This is placed as close as possible to the deflecting plates of a cathode-ray oscilloscope tube in a light-tight box. The timing and delay circuits are analogous to those used in the method already described. To provide a wide field of view, the mirrors are in duplicate; consequently, a moderate change in the expected position of the exploding bomb will not affect observation of the Teller light.

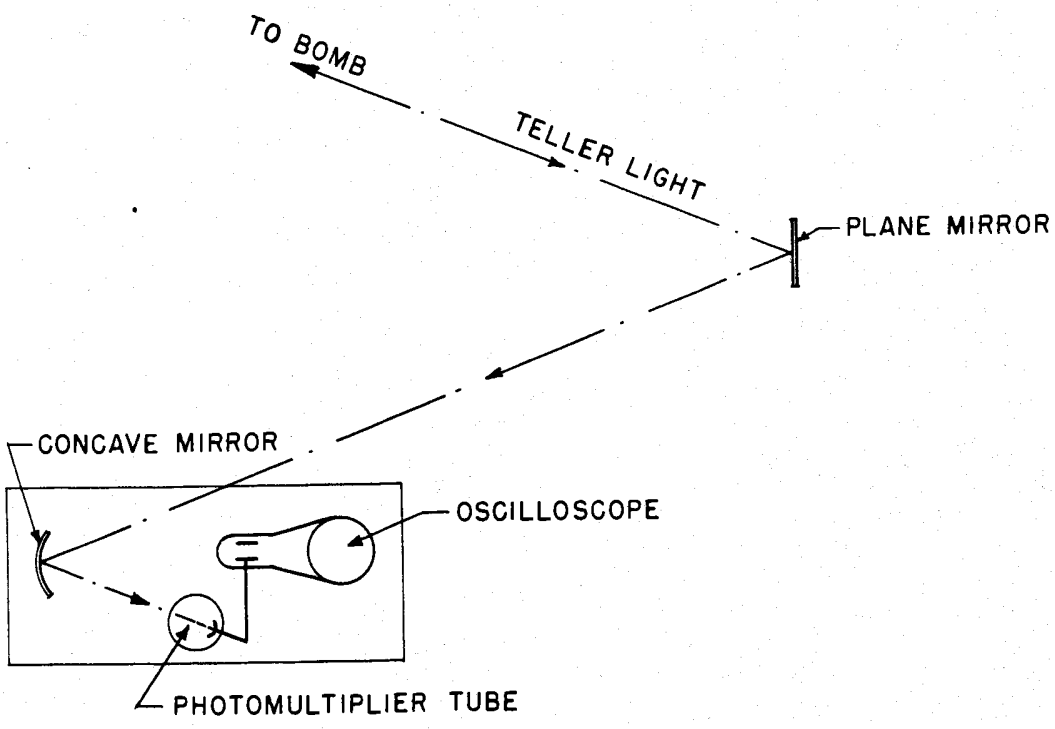


Fig. 6.5

The fission products which have been used most extensively in efficiency measurements are molybdenum-99 (half life 67 hours) and zirconium-97 (half life 17 hours). These isotopes have convenient half lifes, and their fission yields, which are among the largest, are not greatly dependent upon the energy of the neutrons causing fission. The λy values for molybdenum-99 are almost identical for fission of uranium-235 and plutonium-239, so that no correction is necessary if the bomb core contains both of these fissile species. For this and other reasons, molybdenum is the preferred isotope. For zirconium, the λy's are slightly different and the value used to determine f depends upon the composition of the core.

The fraction θ of the bomb in the post-shot sample can be determined by analyzing for one of the major constituents, e.g., uranium-235, plutonium-239, or total uranium, and correcting for the amounts lost in nonfission reactions, such as (n,γ), (n, 2n), etc. Since the total amount of each of these species present in the original bomb is known, the fraction of the bomb in the sample can be calculated.

Another method for determining the fraction of the bomb in the post-shot sample makes use of a different principle. A radioactive tracer, in known amount, is included in the bomb before detonation. If the quantity present in the post-shot sample is then measured, the fraction of the bomb in the sample can be calculated. The supposition is here, of course, that the tracer is uniformly distributed throughout the whole of the bomb residues, and this may not be the case. Measurements of this kind have been made with polonium-210 as tracer, but with indifferent success. Nevertheless, it is proposed to make further determinations with this isotope and also with curium-242 as tracer.

Determination of Fraction of Fissions in U-235, Pu-239, and U-238

It is of interest to know what proportion of fissions has occurred in uranium-235, plutonium-239, and uranium-238, respectively. Radiochemical methods have been developed for this purpose, although they are not too accurate. The fraction of the total fissions involving uranium-235 is represented by a, the fraction in plutonium-239 by b, and that in uranium-238 by c, so that

$$a + b + c = 1. \qquad (6.5)$$

Hence, if any two of a, b, c are determined, the third is known.

The value of c can be obtained by utilizing the experimental fact that the ratio of the cross section for the U^{238} (n, 2n) U^{237} reaction to that for the fission of uranium-238 is roughly constant, independent of neutron attenuation in the uranium. Hence, if the amount of uranium-237 in the bomb residue sample is measured, by means of its radioactivity, the number of uranium-238 nuclei which have undergone fission, and hence, c, can be calculated.

same in both cases, and appropriate corrections must be made for any differences.

According to the theory of strong shocks, the rate of propagation of the shock front and, hence, in the present case, the rate of increase in the radius or diameter, D, of the ball of fire, is given by

$$D = kt^n, \tag{6.8}$$

where k, for a particular bomb, is a constant related to the yield,* and the exponent n is dependent upon γ, the ratio of the specific heats of the material at the shock front. When γ is 1.4, the value of n is close to 0.4, and then equation (6.8) can be written as

$$D = kt^{0.4}. \tag{6.9}$$

It appears that k is roughly proportional to $Y^{1/5}$, so that a good approximation when n is 0.4, has been found to be

$$Y = C\rho_o k^5 = C\rho_o \frac{D^5}{t^2}, \tag{6.10}$$

where C is a constant determined from observations on the balls of fire produced by bombs of known yield; ρ_o is the density of the ambient air.

To use equation (6.10) for the determination of yields, the data for D at various times t, obtained from the Rapatronic camera films, are plotted and the point found at which n in equation (6.8) is 0.4. Upon substituting the corresponding values of D and t into equation (6.10), the yield can be calculated.

Recently a new, absolute (analytic) method for obtaining yields, independent of scaling principles or knowledge of yield of other bombs, has been developed. It permits the calculation of the total energy produced in the nuclear explosion at any time up to breakaway, using hydrodynamic and thermodynamic principles. According to this method, which takes into account such factors as the transport of radiation in the early stages of the development of the shock front, the large mass of the bomb, and time variations in the equation of state of air and in the ratio of the specific heats at the shock front, the yield may be represented by

$$Y = \frac{F}{32}\rho_o n^2 \frac{D^5}{t^2} \tag{6.11}$$

*The factor k is generally represented by ϕ, but this symbol is used here for the efficiency.

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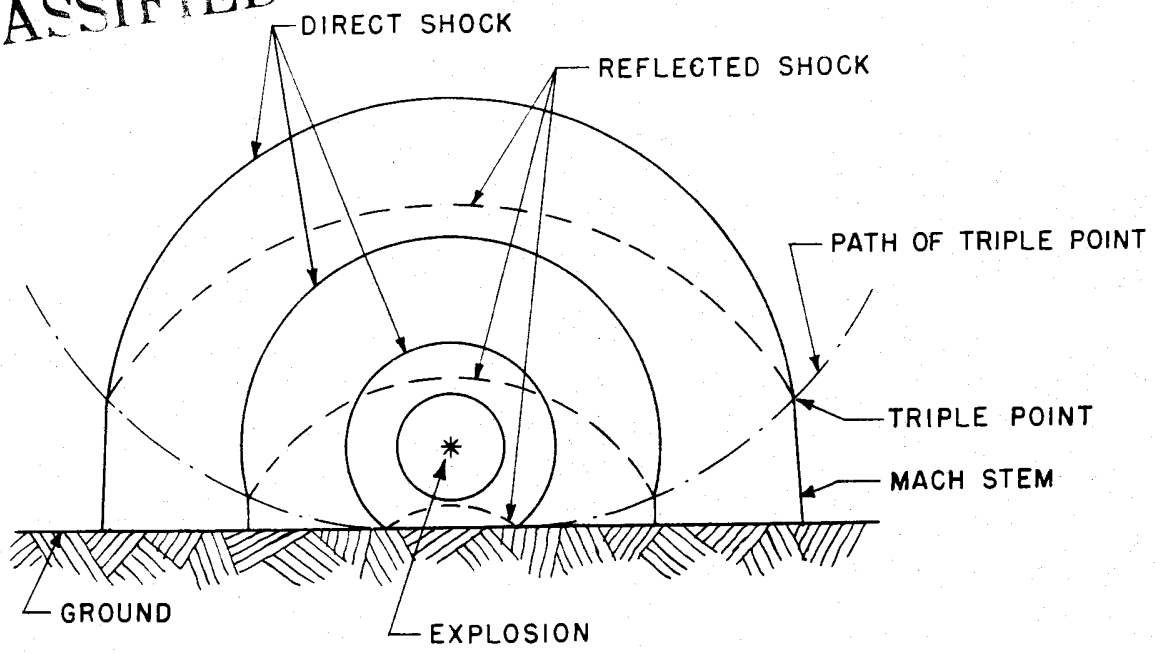


Fig. 6.7

Free-Air Peak Pressure

The shock pressures in the air above the triple point path, i.e., where the Mach effect is not apparent, are called the free-air pressures; these can be determined by observing the time of arrival of the shock front at a series of points at known distances from the explosion. From these times of arrival the shock velocity can be determined and the maximum or peak pressure at various distances can then be calculated from shock-wave theory.

One method used for observing shock arrival times was to attach blast switches to a number of cables held by balloons. Upon arrival of the shock, the switch closes and sends a signal to a distant receiving station, by cable or radio. This procedure has been found to be rather expensive and so it has been replaced by the method of rocket-trail photography.

In passing through a region occupied by a shock front, light is refracted, so that objects seen through the shock wave appear to be distorted; this fact permits times of shock arrival to be determined. Just prior to the explosion, a fan-like grid of vertical smoke trails is produced from a number of rockets launched from the ground at various distances from the zero point. These trails are photographed with a motion-picture camera, at about 100 frames/sec. The arrival of the shock front at a point between the camera and any trail is indicated by an

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apparent shift in position of the trail due to refraction. The method can be used to determine shock pressures as high as 10,000 psi.

Material Velocity Measurements

Material velocity or mass-motion studies have been found to be a useful means of determining free-air peak pressures as a function of distance and also as a means for studying many hydrodynamic variables associated with shock waves. The general principle of the mass-motion method is to label a parcel of air with smoke and then to record photographically, with a motion-picture camera, the movement of the visible cloud when struck by the shock wave. From the displacement of the cloud and the camera speed, a displacement-time curve can be obtained. The maximum slope of this curve gives the material velocity associated with the peak shock pressure. Then from the shock-wave theory, this pressure can be calculated. The mass-motion procedure is probably most valuable at distances where the shock pressure is not too high.

Three methods have been found satisfactory for labeling a region of the air with smoke. These are, first, the use of a jet-assisted take-off (JATO) unit on the ground, with its nozzle pointing upward. Upon ignition this produces a vertical column of white smoke, extending for about 150 feet, which can readily be photographed. The second method utilizes aerial, fireworks bombs ("aerial salutes"); these are fired vertically from a mortar and produce a visible puff of smoke at 100 to 350 ft in the air. Finally, for considerable heights above the ground, smoke shells, fuzed to explode at the desired altitude, are shot from a 90-mm antiaircraft gun.

Mach-Region Peak Pressures

The rocket-trail method described above has been found to give information concerning the Mach triple point path and the shape of the Mach stem in its early stages, as well as of pressures in the Mach region. For studies at or near ground level, arrival times can be determined by means of blast switches or by various methods of direct pressure measurement. Such direct observations are usually restricted to shock pressures below about 100 psi. Several types of pressure gauge have been used for this purpose with more or less success. Mention may be made of foil, indenter, and Wiancko gauges.

The foil meter has a series of thin metal diaphragms of different diameters, so that different pressures are required to rupture them. The maximum diameter not ruptured indicates the maximum shock pressure at that point. In the indenter gauge, the pressure is determined from the indentation produced in a sheet of copper. However, at the present time it is believed that the Wiancko guage, which is a modification of the Bourdon pressure gauge, will prove most satisfactory.

fireball surface, is of special interest. This has been referred to in Section 6.3 as the prompt or effective thermal radiation. The latter description is applied because it is this radiation which is responsible for skin burns, and possibly of fires out to considerable distances from a nuclear explosion. Prompt thermal radiation studies are thus of interest, not only because they provide information concerning the phenomena of a nuclear explosion, but also because of the importance of these thermal radiations from the weapons standpoint. Measurements are usually made of the total energy released as prompt thermal radiation and of the energy variation with time.

The total prompt thermal radiation is measured in two ways. One method makes use of a conventional ballistic thermocouple, the output of which is measured with a thermopile recorder connected to a photoelectronic galvanometer. In the other method a blackened container is filled with air which expands, due to the temperature increase, when radiation is absorbed. The amount of the latter is calculated from the movement of a diaphragm indicator. By using data for the transmission of radiation by the atmosphere just prior to the explosion, such as those described earlier, the total energy liberated by the bomb as prompt thermal radiation can be estimated.*

It was thought at one time that a definite fraction of the energy of the explosion appears as prompt thermal radiation. More recent measurements have shown, however, that this fraction varies with the bomb yield. The results can be expressed, to a fair degree of accuracy, by the relationship

$$Y_{th} = 0.42Y^{0.9 \pm 0.04} \qquad (6.14)$$

where the prompt thermal radiation yield, Y_{th}, and the total bomb yield, Y, are expressed in kilotons. It follows, therefore, that for a 20 kt bomb about 28 per cent of the energy is released as prompt thermal radiation, but in a 100 kt bomb the proportion is only 23 per cent.

The amount of radiation energy, Q, delivered per unit area at a distance D from the explosion is represented by

$$Q = \frac{Y_{th}}{4\pi D^2} e^{-kD} \qquad (6.15)$$

where k is the attenuation coefficient of the air for the thermal radiation emitted in the explosion. The value of k, which determines the transmission of radiation, depends on the state

*The transmission coefficient depends to a marked extent on the wavelength of the radiation and this must be taken into account in the calculation.

Because of the very short exposures, the attenuation of light between the ball of fire and the camera, several miles away, is very important. It is necessary, therefore, to monitor the light path prior to the test shot, by the method already described, if high-speed photography is to be used for ball-of-fire measurements.

Rotating Mirror (Streak) Cameras

The rotating mirror, streak cameras used in weapons tests are essentially the same as those described in Chapter 4 for testing detonators and HE lenses. A rotating mirror reflects light continuously from a number of sources on to a film strip; the distance between the points at which the traces from the different sources commence is a measure of the time interval between the initiation of the respective sources. The writing speed is such that 2 mm is equivalent to 1 μsec. The essential purpose of the streak cameras in weapons tests is thus to determine elapsed time between two or more events.

One such use is to measure the time interval between the fission and fusion reactions in separate parts of a two-stage thermonuclear device. Each type of process will induce Teller light (see Section 6.4) in the surrounding air, so that two streaks will appear on the camera film. The distance between the beginning of the two streaks gives the time between the two reactions.

Another application of the rotating mirror, streak camera is to determine shock velocity and pressure within a device by studying so-called "hot spots." These are points (or small areas) down the length of a case at which the arrival of the shock front from a fission bomb is indicated by strong light emission. By means of a pipe and mirror arrangement, the camera observes only certain selected points, the light from all other parts of the bomb being blocked out. From the positions of the streaks indicating the arrival of the shock front at successive points a known distance apart, the velocity and shock wave and, hence, the shock pressure can be calculated.

The propagation of the shock wave through a particular metal, which is part of the bomb case, can also be studied by the hot-spot procedure. This is done by making the shock wave traverse different thicknesses of the metal, by drilling the bomb case at some points and adding pads of the same material at others. The various spots will thus become luminous at different times and the intervals between them can be estimated from the camera streaks.

6.10 Thermonuclear Burning Studies

Tenex Measurements

The primary purpose of the Tenex (temperature neutron experiment) measurements is to make use of the 14-Mev neutrons produced in the D-T reaction to estimate the thermonuclear

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burning temperature. Strictly speaking, these neutrons have an energy of 14 Mev only if the reacting deuterium and tritium nuclei are at rest. But if these nuclei are in motion, the neutron energy will be 14 Mev plus four fifths of the kinetic energy of the reacting particles in the center-of-mass (C-of-M) system. Actually the center of mass is in motion relative to the observer, so that there is a Doppler energy shift superimposed on the energy in the C-of-M system. Consequently, neutrons released in the D-T reaction will have energies covering a band in the vicinity of 14 Mev. The higher the velocity of the particles, i.e., the higher the nuclear temperature, the broader the band. The velocity distribution is roughly Gaussian, with the half width depending on the temperature.

A scintillation detector is placed at a considerable distance from the explosion, so that neutrons of different energies belonging to the 14-Mev group arrive at different times. These are recorded on a synchroscope, and the velocity distribution can then be determined from the observed "times of flight." From this distribution, the temperature of the thermonuclear reaction system can be estimated. *

When studying thermonuclear devices of high energy yield, the recording instruments must be located a considerable distance away. If the detectors can be placed near the explosion point, long cables are necessary to transmit signals to the recorders. Such lines must be protected from extraneous gamma radiations by extensive earth fills which are costly. On the other hand, if the detectors are close to the recording instruments, the radiations from the bomb, e.g., neutrons and gamma rays, suffer considerable attenuation due to absorption, so that weak signals are received.

In the Ivy tests the problem was solved by transmitting the radiations through a helium channel since this gas is a poor absorber for both neutrons and gamma rays. The channel consisted of a plywood box, 8 ft by 8 ft in cross section and nearly 9,000 ft long, filled with a number of thin-walled polyethylene balloons containing helium gas at slightly above atmospheric pressure. Lead baffles inserted in the box served to provide a number of well-collimated paths, which were used for Tenex and other measurements related to thermonuclear burning.

In order to reduce attenuation still further, an evacuated metal pipe, 6 inches internal diameter and about 7,500 feet in length, is to be used as the radiation path in the Castle tests. A pressure of 0.1 atm is believed to be adequate for the purpose, although it is expected that a much higher vacuum will be maintained.

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*The energy distribution can also be determined, and the temperature estimated, by the Phonex measurements described in Section 6.6.

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Gamma-Ray Experiment

A method for studying the time characteristics of D-T burning makes use of the gamma radiation accompanying the reaction. In this experiment it is essential that the gamma-ray beam should be well collimated and that the collimator should point at the region of the bomb where the thermonuclear processes are occurring. The gamma rays are observed by means of a scintillation detector connected to an oscilloscope; the time variation of the observed signal is then directly related to the progress of the thermonuclear burning.

For the George experiment (Operation Greenhouse) the detector was placed near the device and the signal was carried by buried cables to the oscilloscope which was not too far away. In the Mike (Ivy) shot, however, for the reasons given above, the gamma radiation was transmitted through a collimated channel in the long helium-filled box described earlier. For the Castle tests, the vacuum pipe referred to above will be used.

X-Ray Experiment

Nuclear reaction temperatures can be determined by utilizing the fact that at these temperatures the "thermal" radiation emitted is in the soft X-ray region, with energies in the range from 1 to 10 kev. From the energy or wavelength of this radiation, it is possible to estimate the temperature of the emitter. The method is usually not applicable to fission bombs because of the considerable absorption of the X-rays by the bomb materials. But for certain thermonuclear devices, where the absorption is not so great, the X-ray method can be used to derive reaction temperatures.

There are several difficulties associated with the measurements, among which may be mentioned the following: the 1 to 10 kev region has been little studied; a very high time resolution is required because of the rapidity of the thermonuclear burning; and the detecting devices must cover a wide range of intensities. The method used with some success at the Greenhouse tests was to permit the "thermal" X-radiation from the experimental device to travel down an evacuated pipe and to fall on a detector, called a fluorescer. This is a foil coated with a compound of either potassium, manganese, or copper; these elements are sensitive to X-rays in the regions just above 3.6, 6.5, and 9.0 kev, respectively.

If X-rays of the appropriate energy strike the fluorescer, one of the K-electrons of the element present will be ejected; when its place is taken by another electron, the characteristic K-radiation of either potassium, manganese, or copper will be emitted. This is allowed to fall upon an aluminum surface shielded from the direct X-ray beam, and as a result photoelectrons are produced. The electrons are accelerated by a high voltage and the resulting signal can be recorded on an oscilloscope. By observing which of the fluorescers produces its characteristic X-radiation, an estimate may be made of the energy of the primary (thermal) X-rays and hence of the temperature of the material emitting them.

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Sigma 3-1

HISTORY OF THE EARLY THERMONUCLEAR WEAPONS

Mks 14, 15, 16, 17, 24 and 29

SC-M-67-661

Information Research Division, 3434

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ATT 3



Mk 17 thermonuclear weapon

13.5 megaton Castle-Yankee aboard barge over Union crater near Yurochi Island, Bikini Atoll (surface burst)

40% Li6, 60% Li7; 52% fission

hydrogen bomb should or should not be developed, the President directed the Atomic Energy Commission to continue its work on all forms of atomic weapons, including the so-called hydrogen or Super bomb. Work on Super was accordingly accelerated, only to be retarded again in mid-1950 when the outbreak of the Korean War re-emphasized the need for small nuclear devices.

The Air Force made early plans to carry and deliver large and heavy hydrogen bombs and, in 1950, established two projects, Brass Ring and Caucasian. Brass Ring envisioned carriage of the weapon in an unmanned drone B-47, which would be guided to a target by a mother ship and destroyed in the detonation. This project was given considerable support, due to uncertainty concerning the possible yield of a hydrogen bomb, then estimated to lie between 10 and 40 megatons.

[redacted]

This possibility was discussed at a conclave of scientists and AEC representatives June 19, 1951, and it was concluded by the attendees that a practical thermonuclear weapon was achievable, using radiation energy as a compressing force.

Due to some personal differences of opinion, Teller proposed the creation of a new physics laboratory to develop thermonuclear devices. He was supported in this stand by the Air Force, which offered to provide a suitable laboratory. Subsequently, the

[redacted]

AEC established a laboratory at Livermore, California, under the administration of the University of California. The contributions of the University of California Radiation Laboratory to the early development of thermonuclear weapons were somewhat meager, except that the existence of the laboratory helped to encourage the over-all program.

[redacted]

The computational work involved in analyzing the thermonuclear process was a colossal task, and could not have been accomplished without the great advances in computing equipment that took place in the late 1940's and early 1950's. The IBM 601 was considered quite a machine in 1945, but it was far surpassed by the Maniac, designed at the Institute for Advanced Study, Princeton, New Jersey, and which became available in 1952. A problem that would require 3 months work by the 601 could be solved in 2 days by the Maniac. It is of record that, in the course of running a thermonuclear problem on the Princeton Maniac in 1953, the number of basic arithmetical computations performed was of the same order of magnitude as the total number of similar operations performed at Los Alamos (excluding those done on the Los Alamos Maniac) in the entire 10 years of operation of the Laboratory.

The first task assigned to the Los Alamos Maniac was to perform more exact and extensive calculations of the thermonuclear process. The theory of radiation implosion was refined and reinterpreted, and the flow of radiation pressure along channels between the fission and fusion components of the bomb was determined.

[redacted]

Sandia and Los Alamos forwarded a joint letter to the Division of Military Application May 22, 1952, proposing that the TX-14 be designed with the following guidelines:

[redacted]

1. Maximization of yield to the point where escape of a manned transporting bomber was impossible (the use of an unmanned drone had meanwhile been discarded), or production of the largest yield possible in the size allowed.

2. Diameter not to exceed 64 inches; length, about 20 feet; and weight, about 50,000 pounds. (This made the TX-14 comparable in length and weight to the World War II Block Buster bomb which was 27 feet long and weighed 44,000 pounds).

3. Bomb to be capable of withstanding forces involved in careful handling, aircraft loading and carrying, and free or retarded fall.

4. Bomb to have a capability for air-burst operation only.

[redacted] b(3 Do

The term "emergency capability" was defined to mean that there would be no factors that would prevent carriage of the TX-14 in manned aircraft. No "gold-plated" engineering would be done, operational suitability tests would not be conducted, information on reliability would be lacking, no inflight insertion device would be provided, and assembly and use would require the services of trained scientists and engineers. These TX-14 emergency-capability devices would thus be in a state corresponding to the Little Boy and Fat Man bombs at the time of their use in World War II.

Los Alamos was assigned overall responsibility for the TX-14, and Sandia would provide the ordnance engineering. [redacted] b(3 DOE

The Division of Military Application forwarded this proposal to the Military Liaison Committee, which replied, June 13, 1952, that the Joint Chiefs of Staff

had established a military requirement for the development of thermonuclear weapons with yields of 1 megaton and over, requesting that these weapons be compatible in size, shape and weight with delivery systems that would be available in 1954. Production facilities for thermonuclear materials would be developed immediately. It was felt that any prior production of a deliverable thermonuclear weapon by the Soviet Union would reduce the existing American lead in weaponry, and that such a shift in balance might well cause a change in Soviet policy. This factor alone provided adequate justification for an approach involving considerable technical risk and a large expenditure of funds.[11]

[redacted]

By November 1954, all emergency-capability units had been modernized to Mk 17/24 Mod 0 status. The design did not differ in any important aspects from the TX-17, but the components were of certified stockpile quality. The Mk 17/24 Mod 0 Bombs thus became the first thermonuclear weapons to be stockpiled as a result of a regular production program.

The weapon could be carried and dropped by a B-36, if the release was made at an altitude of 40,000 feet or higher. Lower altitude releases, into denser air, would produce high-shock loadings. The B-52 could not be used as a carrier due to its high speed, which also created high shock loadings at release.[78]

It was noted in the May 21, 1954 meeting of the TX-Theta Committee that heavy production rates had been authorized for Mk 17/24 Bombs in late 1954, and it was suggested that as many improvements as possible be incorporated prior to that date. [redacted] b(3) DoE

A Mk 7-type automatic inflight insertion mechanism was to be used, and this redesign required some lengthening of the bomb nose. Sandia ran a wind-tunnel check, which showed that little effect on weapon stability resulted. The Mod 0 of the Mk 17/24 was not exactly a model of aerodynamic stability, as it oscillated with an amplitude of about 10 degrees during its fall, even with parachute retardation, but the nose, which was 2 inches longer, did not aggravate this effect.

[redacted] b(3) DoE.

Additionally, the tail fin of the TX-15 was changed at this time from an all-metal design to one of composite metal and plastic, and this change was also made in the Mk 17/24 Mod 1.

[redacted] b(3) DoE

It was relatively simple to design contact fuzes for fission weapons, since these devices were covered with a light ballistic fairing that was able to sense the shock of impact and signal detonation before any real physical damage was done to the weapon. However, in thermonuclear devices, the heavy case would have to sense the impending shock and detonate just before actual impact took place.

Discussions with Los Alamos led to the conclusion that the secondary reaction would occur if the primary reaction was completed, and it was decided to use a barium titanate crystal contact fuzing system developed for fission bombs.[83] Sandia performed some sled tests in Area III, from which a design was evolved using two networks each containing two impact crystals, mounted on the nose of the bomb. A fast-firing gap-type X-unit was concurrently developed.

Further work on parachutes was necessary, in order to produce a design which would permit releases from B-52 bombers and result in a down-time of 75 seconds. Sandia placed an order on Wright Air Development Center for both standard and heavy-duty parachutes with diameters of 40 feet. The first phase of this testing program was completed January 19, 1955, after eight drops had been made with standard chutes. Test results showed that opening shocks were lower than expected. However, the requirement for carriage in the B-52 was canceled April 24, 1956, due to release troubles in which the suspension sling failed to retract properly. Subsequently, the Strategic Air Command decided to use a 64-foot-diameter chute and to place an operational restriction of 365 knots airspeed and 20,000-foot altitude on the weapon at release.

The Mk 17/24 Mod 2 Bomb was design-released June 1, 1955. The weapon contained a Mk 17 Mod 0 Fuze, with both contact- and air-burst capabilities. The bomb was 61.4 inches in diameter, 298 inches long, and weighed 42,000 pounds. [redacted] b(3) DoE

The weapon could be stored for 18 months under stockpile storage

[redacted]

conditions, and for 15 days as a ready weapon. Efforts were under way to increase the latter figure to 30 days, to meet the desired ilitary characteristics. A 6-month capability was desired for the fuze, normally stored in its own sealed container, and the attainment of this goal appeared hopeful.

Prior to dropping the weapon from the bomber, a safing switch was closed. Release of the weapon resulted in closure of the pullout switches, and weapon power was applied to the electrical system of the bomb. Parachute deployment was now initiated, if this option had been selected. At the selected arming altitude, an arming baro closed and started the charging of the X-unit. At the selected height for air-burst operation, the firing baro closed and detonated the bomb by firing the trigger circuit. The contact fuze acted as backup in the event of air-burst fuze failure, or it could be selected as the fuzing option. [redacted] b(3) DoE

[redacted]

About 25 percent of the Mk 17 stockpile was converted to the Mod 2 configuration. The work was performed at sites by the Military under Sandia supervision during the period June to August 1956. The program which would have resulted in the Mk 24 Mod 2 was canceled, and by October 1956 all Mk 24's had been retired in favor of the Mk 36 design.[22]

The Mk 17 Mod 1 weapons were retired between November 1956 and August 1957. The Mk 17 Mod 2's were retired between August and October 1957, since Mk 36 weapons were then entering the stockpile in large enough quantities to fully support military plans for weapons of this yield range. The Mk 36 provided a higher yield than the Mk 17 and at a much lesser weight.

LA-14066-H
History

Tracing the Origins of the W76: 1966–Spring 1973 (U)

Betty L. Perkins

November 3, 2003

[See p. VI-69 for Harold Agnew's complaint that the Polaris / Trident MIRV SLBM W76 warheads in Polaris and Trident are merely "threatening to throw confetti at a potential aggressor." Unlike neutron bomb W79-1, the W76s didn't deter the Russians from escalating Cold War, by invading Afghanistan in 1979.]

NUCLEAR WEAPON DATA
Sigma 1
Critical Nuclear Weapon Design Information
DoD Directive 5210.2 Applies

RESTRICTED DATA
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July 14, 2003

Los Alamos
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Los Alamos NM 87545


TRIDENT II SLBM LAUNCH

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TRACING THE ORIGINS OF THE W76: 1966–SPRING 1973

by

Betty L. Perkins

ABSTRACT (SRD)

The objective in writing this report was to place the development of the W76, before it entered Phase 3, in a historical perspective. The author has rather arbitrarily chosen to consider for this pre-Phase 3 history, the history of the weapon program at Los Alamos during the years 1966–May 1973.

The report tries to provide some understanding as to why, in the spring of 1973, the Los Alamos Scientific Laboratory received the Phase 3 assignment and why the assignment was important to the future of Los Alamos. In addition, the report provides insight into why historically the design of the W76 evolved as it did.

Chapter I provides general information including the organization of the Laboratory during the time-period of interest and the definition of what is included in the different phases in weapon development.

Chapter II discusses the work on primary design.

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Chapter IV briefly describes the early development effort for several of the materials that would be important in the W76 program.

(b)(3) The engineering status of several ancillary components such as detonators and gas storage systems is reported. Chapter IV notes the vulnerability tests relevant to the early LASL XW76 weapon program.

Chapter V includes a brief discussion of the history of the weapon systems assigned to Los Alamos as Phase 3 programs during the 1966–spring 1973 period. The extensive effort that was required for the various Phase 1 and 2 programs and the early advanced development programs under consideration during these years is also discussed. It is noted that despite this effort, the Los Alamos weapon teams failed during 1966–1972 to win a viable Phase 3 assignment to develop a warhead for a strategic missile weapon system. The chapter also includes some trends in the U.S. nuclear stockpile that are important in understanding the 1970–1980s weapon programs.

Chapter VI outlines the Los Alamos effort for the Mk 18 and the later Mk 400 programs; programs that served as the precursor programs to the W76. This chapter provides insight on the Los Alamos effort to obtain a Phase 3 assignment for a strategic warhead and the success in this effort that resulted in the long desired award of the XW76 program to Los Alamos.

CHAPTER I. INTRODUCTION

A. Explanation

1. Assignment

The assignment given to the author was to outline the history of the development of the W76 warhead (presently carried on both the Navy's Trident C4 and D5 submarine-launched ballistic missiles). Because the Los Alamos Scientific Laboratory [LASL] received the Phase 3 assignment for this warhead in the spring of 1973, it would be reasonable to assume that a history of the W76 would cover only the period from the Phase 3 assignment until the initial operational capability of the W76 was achieved in October 1979 (Poseidon back-fit). But history is continuous. What happens at one point in time is dependent upon what happened earlier.

In order to set the development of the W76 in the necessary perspective, give some understanding as to why in the spring of 1973 LASL received the Phase 3 assignment and why the assignment was important to the future of Los Alamos, and indicate several reasons why the design of this device evolved as it did, a history of work prior to 1973 is required. The author has rather arbitrarily chosen to consider for this history, the history of the weapons program at Los Alamos during the years 1966–May 1973. (However, to give continuity, some aspects of the program are also described for work completed before 1966.) This pre-Phase 3 effort at Los Alamos is the focus of this report.

However, the author must insert a warning to the reader. It must be noted that to further increase the complexity that is history, it is almost impossible to identify all the factors that go into determining actions during a specific era. In addition, the description of an event is dependent upon the available "data set" of historical documents. Moreover, how an event is described in a point in time is dependent on what happens later and on our own personal experiences, knowledge, and "mindset." Thus, no history can be completely objective.

2. Overview

Before the award of the design effort for the W76 to Los Alamos, the U.S. nuclear weapon designers had been required—by the introduction of MIRVed (Multiple Independently Targeted Reentry Vehicle) missiles into the U.S. weapon arsenal—to develop lightweight/small warheads for use in the missiles' reentry vehicles.

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Chapter IV will briefly describe the early development effort for several of the materials that would be important in the W76 program.

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The engineering status of several ancillary components such as detonators and gas supply systems will be reported. Chapter IV will also note the vulnerability tests relevant to the LASL XW76 weapon program.

Chapter V will outline and briefly discuss the history of the weapon systems assigned to Los Alamos as Phase 3 programs during the 1966–1972 period. In addition, mention will be made of Phase 1 and 2 programs and early development programs under consideration during those years. This chapter will attempt to inform the reader as to the extensive effort that was required. However, as Chapter V will also describe, the Los Alamos weapon teams failed during 1966-1972 to win a viable Phase 3 assignment to develop a warhead for a strategic missile weapon system. The W62 for the Minuteman III with a Phase 3 of 1964 went to Livermore. The W68 for the Navy's Poseidon submarine with a Phase 3 of 1966 also went to Livermore. Earlier, the W56 (the warhead for the Minuteman I, II) and the W58 (the warhead for the Navy's Polaris) had also gone to Livermore. The Chapter will also note some trends in the U.S. nuclear stockpile that were important for the weapon programs at the Livermore, Sandia, and Los Alamos laboratories.

Although the program was finally canceled, of particular importance to the later W76 development was the Mk 18 program. This program will be covered in some detail in Chapter VI. The Navy's Mk 400 program was the precursor program to the W76. The history of *the Mk 400 program will also be outlined in Chapter VI. This chapter will discuss the vital* question: who would win the Phase 3 for the Mk 400 (XW76) Los Alamos or Livermore?

B. Los Alamos Scientific Laboratory Management Structure and Philosophy

1. Norris Bradbury

Norris Bradbury served as the director of the Laboratory at Los Alamos from October 1945 until September 1970. When he accepted this job and became director in October 1945 just after the end of WWII, he promised that he would serve for six months. But the six months of service stretched into twenty-five years.

In a January 1967 letter to Charles Winter, Deputy Director of the Division of Military Application, Bradbury described the Laboratory, "Los Alamos is organized on a facility and technology basis; LRL is organized more on a project basis." Bradbury also noted, "Internally in the Laboratory, the weapon program is steered by a committee chaired by the Laboratory Director and comprised of Assistant Directors and relevant Division Leaders. Basic decisions are made by this group, the members of which carry the authority within their respective areas of responsibility to implement them. More detailed discussions and decisions within the framework

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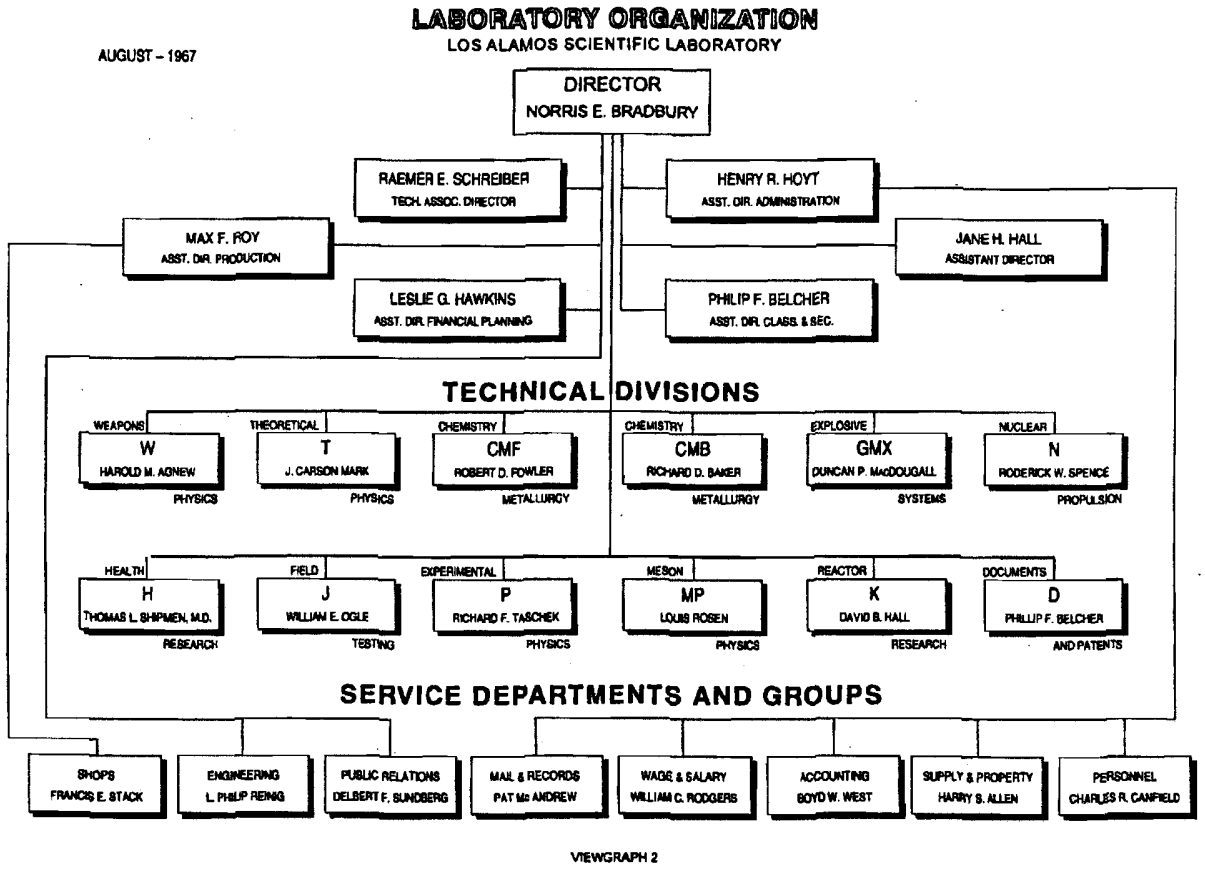


Figure I-1. Laboratory Organization August 1967
Source: "Summary, SAC Briefing, August 15, 1969," W-9-481 (U) (August 25, 1969), p. 8, A99-019, 215-17.

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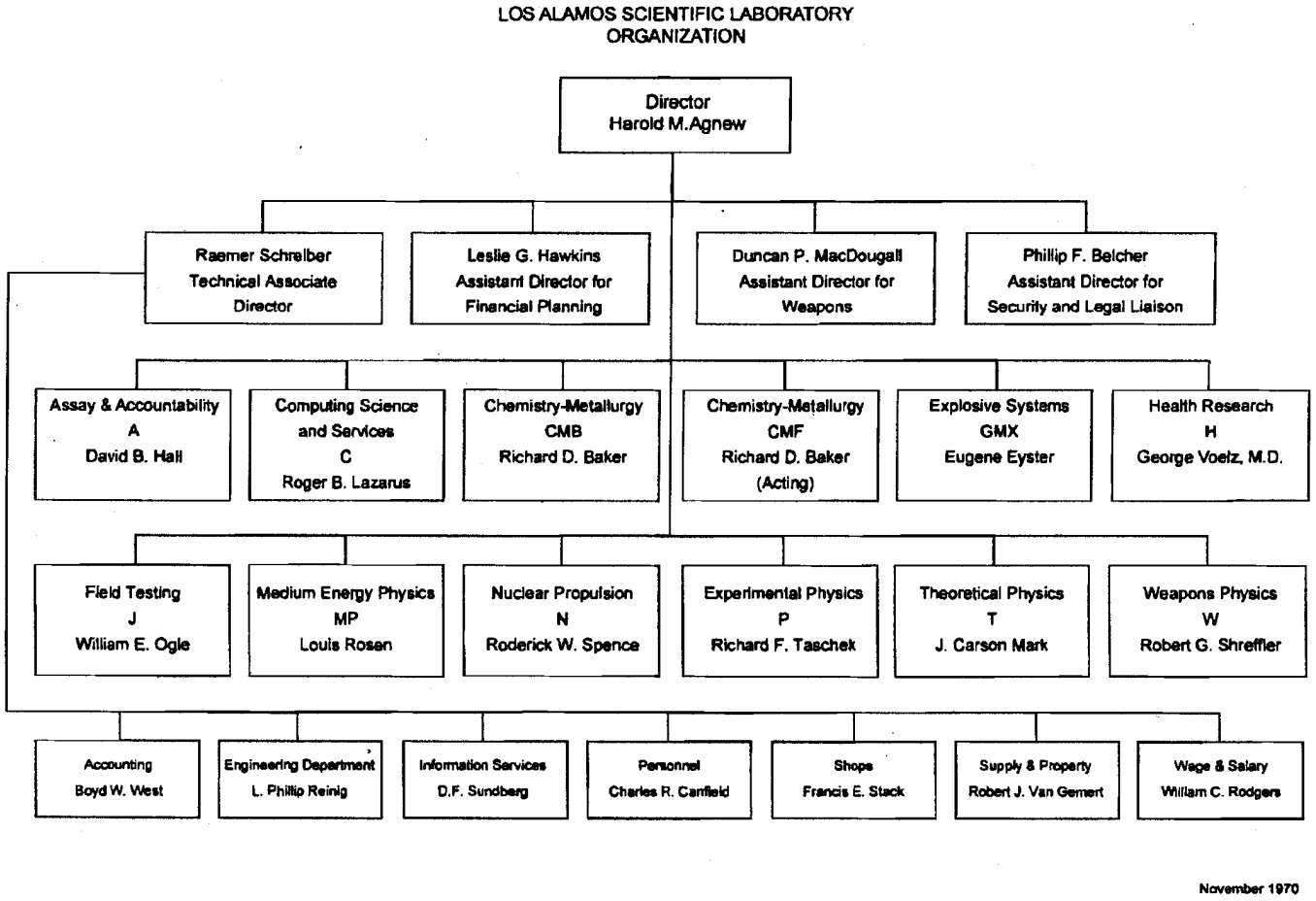


Figure I-2. Laboratory Organization November 1970
Source: "Los Alamos Scientific Laboratory Organization," (U) (November 1970), 1 p., A88-011, 2-30.

made by the Defense Department. It we weren't providing the technology that allows these high yields in smaller packages to be made we wouldn't be keeping up with the Soviets because the number of Minuteman we have is the same and the number of submarines is the same. It is the warhead technology that enables this country to keep up its deterrent, and that is only because of the technological base which the weapons laboratories supported by the Committee and the Commission provide the country."[4]

As part of his new job as director at Los Alamos, Agnew would continue and intensify his campaign for Los Alamos to receive the Phase 3 assignment for the W76. He was successful in this effort.

C. Weapon Group Designations/Responsibilities, Support and Basic Research Groups, and Committee Functions

As noted in the organization charts of Figures I-1 and I-2, the work at Los Alamos took place along the lines of various disciplines. A set of Divisions, each concerned with a particular interest was set up. In each Division there were groups where the work was again more narrowly specified. However, to produce a specific weapon, members from all the different divisions came together as needed. The following sections will attempt to explain how the Laboratory functioned in terms of organization.

1. Weapon Groups: 1966–September 1972

a. Weapon Design

Very early in the history of the various groups in the Laboratory (1948–December 1970), W-4 was designated as the small weapons theoretical design group responsible for the design of single-stage devices and primaries. However, in January 1971, a division known as TD-Division, responsible for the theoretical design of nuclear weapons, was created. Group members in W-4 then became group members in what was designated TD-4.

Until the formation of TD- and C-Divisions, members of T-Division were responsible for computing, code development, theoretical problems in mathematics, and some aspects of weapon design. For a number of years, until 1973, Carson Mark was the Division Leader. Another important member of the division office at that time was secondary designer Robert Thorn. Until Thorn became TD division leader in 1971, he also headed T-2. (A "new" T-2 group called the Nuclear Data group was then formed in April 1971.) Formed in September 1959, T-3 was the hydrodynamics group. Until it became TD-1 in January 1971, T-4 (which had become a group in May 1970) was also a weapons group in T-Division. (Beginning in October 1971, the "new" T-4 became the group concerned with equation of state and opacity.) The group T-5 members were concerned with numerical analysis; in January 1971, this group became TD-5. From July 1963 until January 1971, T-6 was the fission weapons design group. [Author's note: This group under Dave Woods was apparently a backup design group for the other design groups. By having multigroups, it was possible to see if the design teams agreed.] Group T-7 was the computer research and development group. In April 1968, its members joined C-Division. Members of T-8 were concerned with applied mathematics (mathematical methods). Their well-known group

[4]"Remarks by H. M. Agnew Concerning Need for Testing," (June 15, 1970 Briefing), DIR-2244 (SRD) (October 9, 1970), pp. 7.6–7.7, A99-019, 269-1.

leader was Stanislaw Ulam. In the January 1971 reorganization, members of this group were split into TD-5 and TD-6. The weapon effects group was T-12—until the group was dissolved in July 1968. Once TD-Division and C-Division were formed, the interests of members of T-Division were those required to provide theoretical and analytical support to most of the major programs of the Laboratory.

C-Division was formed in April 1968 from parts of T-Division and Data Processing. This division was called the Computing Sciences and Services Division. Thus the name indicated the type of work for which the division member's were responsible. Nicholas Metropolis served as an advisor from April 1968 to March 1974. In 1972, the members of C-Division were responsible for maintaining and operating one IBM 7094, two CDC 7600s, three CDC 6600s, two IBM 1401s, and one IBM 1360. In addition, the members' interests included research in statistical theory and development of methodology, consultation, assistance in numerical procedures and techniques for problem solving, numerical analysis, and applied mathematics and programming.

On January 1, 1971, a new division was formed that included the "old" T-2, T-4, T-5, T-8, and W-4 groups. This division was called TD, or the Division of Theoretical Design. Members of the division office included several members of the Los Alamos weapon design team. Robert Thorn was the division leader with Harry Hoyt the alternate division leader. TD-1 was called the Thermonuclear Weapons Physics group. TD-2 was the Thermonuclear Weapons Design group. It was this group that was chiefly concerned with the design of secondaries. TD-3 was Weapons Outputs. Another very important group was TD-4, Small Weapons Design. This group was responsible for the design of single-stage weapons and the primary in multistage weapons. TD-5 was called Codes Development. TD-6 was the Monte Carlo group. Concerning TD activities as of June 1972, it has been reported, "This Division is responsible for the theoretical design of nuclear weapons. The Division is responsible for work on the physical principles of nuclear weaponry, research and development on new concepts, and output effectiveness studies of various classes of weapons. An important portion of the effort is directed toward design and interpretation of nuclear weapon tests. ...The personnel of the Division perform calculations based on fundamental theory but use as a database experimental data from other groups of the Laboratory."

Most of the work in T, C, and TD took place in the main technical area, called TA-3.

b. HE Production and Development and In-House Field Tests

A division called GMX was formed in 1948. This division, divided into a large number of groups, was responsible for explosives and "their interaction with metal." Duncan MacDougall was division leader from August 1948 until September 1970 when MacDougall became Assistant Director for Weapons. [Author's note: It should also be noted that another strong figure in the early weapon program was Max F. Roy. He served in the director's office as Assistant Director for Production from August 1948 until his retirement in June 1970. There is a story that circulates in the laboratory that Max Roy wanted to contract work out, but MacDougall wanted the work done in-house.] Eugene H. Eyster served as alternate GMX division leader between 1954 and 1970 when at that time he became division leader.

GMX-1 was the nondestructive testing group. As will be noted, this group became, in September 1972, M-1. Their main work site was TA-8 (Technical Area 8). This site is known as

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(b)(3)

[Use of linear implosion primary design for small sized W76 design ...]

The basic idea came from Famularo, Juveland, and Cremer; Bernard and Jacoby contributed to the development of the principle in HE-driven systems. It started with a study of gun devices in an attempt to make them lighter and to drive them with lower reactivities." Additional historical information is available in the cited reference.[14]

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[14]Beverly A. Wellnitz, "Weapons Working Group, Minutes of the 215th Meeting," WWG-215 (SRD) (October 29, 1969), pp. 5–6. A99-019. 92-19.

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(b)(3)

The history of the early Livermore design program is the subject of LA-13755-H (SRD), and for more information the reader is referred to this document.

(b)(3)

The Bradbury memo was followed by the establishment of the Small Systems Group. During their first meeting on August 29, 1957, the group members decided that a delegation from Los Alamos should visit Livermore in September.

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a. Military Requirements for Small, Lightweight Warheads

As noted previously, in the mid-1960s the Los Alamos design group had begun work on 10-inch diameter or less primaries.

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The reason for this great interest on the part of the design laboratories in the 10-inch and less diameter was the fact that the Military was pushing for small, lightweight systems. By this period, the missile/guidance/nose-cone establishment in the United States had developed their systems to where it appeared that it would be possible to put several warheads on one intercontinental ballistic missile (ICBM), deploy the missile, and have each of the warheads hit a different target. This concept is referred to as use of multiple independent reentry vehicles (MIRV). It was felt at that time that the USSR was also going into these types of systems. Because a warhead is much less costly than a missile, the Military wanted to pack as many warheads as possible into each missile. This desire for as many warheads as possible on one missile pushed the nuclear weapon groups to achieve as small as possible in terms of diameter. Moreover, the Military wanted as long a range as possible for each missile; this requirement pushed the weapon groups to try and design minimum-weight warheads.

A request for multiple-carriage capability for the forthcoming improved Minuteman system was formalized in a January 1963 revision to the Phase 1 study. Three reentry vehicles were to be carried in this system—designated the Mk 12 (L). On February 12, 1964, Phase 3 authorization was given for the Mk 12 (L). Livermore and Sandia Corporation, Livermore, were to receive the assignment (the warhead would carry the designation XW62). In November 1964, the Military Characteristics were amended to provide a warhead "compatible with a MIRV application on the advanced Minuteman missile system."[95]

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On August 31, 1964, in a letter to AEC Chairman, Glenn Seaborg, Harold Brown, Director of Defense Research and Engineering, formally proposed the lightweight warhead program. Later, a paper titled "MIRV on Minuteman

[95]Betty L. Perkins, "Tracing the Origins of the Modern Primary: 1952-1970 (U)," Los Alamos National Laboratory report LA-13755-H (SRD) (April 2, 2001), pp. XII-7–XII-14.

and Titan II" and dated March 3, 1965, was provided to the administrations at the weapon-design laboratories.

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(b)(3)

1. Loss of the Poseidon C-3 Warhead to Livermore

In March 1965, a paper titled "USN Missile Force Improvement Summary" was published under the sponsorship of the Institute for Defense Analyses. This paper suggested a design for a small reentry vehicle designated the Mk 100 and reported that eight of the Mark 100s could be included in the Navy's Polaris A-3 system.[107]

By April 1965, the Navy decision makers had decided on a new missile to be known as Poseidon. Compared to the Polaris A-3, the Poseidon was to be longer and have a larger diameter, carry a heavier payload, and achieve a greater range. Each missile would carry multiwarheads and would use a space bus to carry and distribute the warheads on target.[108]

A December 6, 1965, letter from the Chief of Naval Operations requested AEC participation in the Poseidon conceptual studies. On the cover sheet of this letter, there is a note written by a person in the Los Alamos management to the effect that Los Alamos had requested that the Navy invite Los Alamos to compete on the Poseidon assignment. The note stated, "...we [LASL] should really go after the business."[109]

On January 13, 1966, Director of Defense Research and Engineering, John S. Foster, Jr., in a letter to AEC Chairman Glenn T. Seaborg indicated that the Navy was favoring the Mk 100-type, small-reentry vehicle with its multiwarheads for use on the new Poseidon C-3 fleet ballistic missile.[110]

Representing the various groups at Los Alamos, on April 28–29, 1966, Peaslee, Aragon, Horpedahl, and Hoverson attended a meeting in Washington on the Poseidon C-3 missile system.

(b)(3)

[107]"USN Missile Force Improvement Summary (U)," Institute for Defense Analyses Pen-X Paper 59, IDA/HQ 65-3610 (SRD) (March 1965), pp. 9–10.

[108]"Weapon Development Status Report (U)," Headquarters Field Command Defense Atomic Support Agency, Sandia Base, Albuquerque, New Mexico report FC/04650121 (SRD) (April 1, 1965), p. 14, A99-019, 160-1.

[109]Harry B. Hahn to Director, Division of Military Application, U.S. Atomic Energy Commission (SRD) (December 6, 1965), 2 pp., A99-019, 217-15.

[110]John S. Foster, Jr. to Honorable Glenn T. Seaborg (SRD) (January 13, 1966), 2 pp., A99-019, 217-15.

(b)(3)

In May 1966, the AEC published a Phase 2 feasibility study for a warhead for the Poseidon C-3 missile system. Proposals from the Los Alamos Laboratory were included in this study.

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Although the Los Alamos group very much wanted the assignment of the Navy's warhead (to be known as the W68), such was not to be the case.

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Bradbury wrote a letter dated June 1, 1966, to Livermore director Michael M. May.

(b)(3)

Bradbury proposed a "pie split"—Livermore would take the Mk 3 Poseidon warhead and Los Alamos would take the warhead for the Mk 18.[113]

(b)(3)

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This decision must have been reinforced after hearing from the Peaslee delegation, when they returned from Washington, as to how badly Los Alamos had come off in the bid for the W68.

(b)(3)

On April 4–5, 1966, a group from Los Alamos composed of William Deal, E. L. Peterson, D. M. Mosher, and Gene Eyster from GMX Division and Bill Davis from W-1 visited Livermore.

(b)(3)

[113]N. E. Bradbury to Dr. Michael M. May (SRD) (June 1, 1966), 2 pp., A99-019, 186-2.

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(b)(3)

1. Initial Considerations

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The Hydrodynamic Committee was assigned the job of naming the proposed primary.[144]

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2. Class Name

Towards the end of November 1967, the problem of what primary to use in the Mk 18 was somewhat resolved.

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[144]Jane H. Hall to Distribution, Subject: "Memorandum of Understanding – WLPC No. 21," AD-1814 (SRD) (November 13, 1967), p. 1, A99-019, 91-10.

(b)(3)

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This means that every detail will have to be worked out in order to design local tests, attachments, etc. He has requested help from Sandia Corporation in this work."

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For example, at the WWG meeting of February 21, 1968, it was reported that LASL had been assigned development responsibilities for the Mk 18. Bradbury commented that LASL had better pursue all versions of the Mk 18. During the meeting various possibilities for the warhead's design were discussed by Peaslee.

(b)(3)

a. Design Program

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During the WWG meeting of March 13, 1968, Osborne explained his work up to that point.

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Diagnostics were to be alpha, time interval, radiochemistry, and on the secondary (1) Pinex

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(originally an acronym for Pinhole Neutron Experiment)—using the television time integrated method; (2) TRAX (Time Resolved Asymmetry Experiment)—time and space resolved measurement of 14-MeV neutron production in the boost region; and (3) RTA (Radiation Time of Arrival)—radiation time of arrival where observation was made of x-rays through a transparent hole in the case. It was noted that the rack design was very complicated and that the design and fabrication schedule was tight.

(b)(3)

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1. Livermore: A Small, Lightweight Secondary

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In the mid-1950s the U.S. Military began to push for smaller, lighter nuclear weapon designs. At Livermore, the secondary design team began work on the design of a secondary suitable for this application.

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This type of lightweight device was the design objective of a UK/U.S. study group called JOWOG-3 (Joint Working Group 3).

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R. Thorn discussed this design concept at the July 16, 1959, meeting of the TWG.[5]

The design was again discussed by R. Pollock during the August 20, 1959, TWG meeting. By now the design was more complete.

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[5]"Minutes of the Third Meeting of TWG," TWG-3 (SRD) (July 30, 1959), p. 4, A99-019, 87-8

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B. Los Alamos 1965–1968 Design Program Involving a Small Secondary

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2. Early Mk 18 Program

a. Options for a Warhead for the Minuteman III Missile

In the mid-1960s the Military began to consider a possible Minuteman III missile that would employ a multiple warhead carriage. The warhead for this application was designated Mk 18.

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In a June 1, 1966, memo, Bradbury proposed to do a "pie split" with Livermore. If Livermore would support Los Alamos receiving the Mk 18 assignment, Los Alamos would not oppose the assignment of the Mk 3, the Poseidon warhead, to Livermore.[35]

In a TWX dated June 23, 1966, AEC Director of Military Application, Delmar Crowson, informed the Laboratories that in order to have different nuclear design approaches for the Mk 3 and Mk 18, he was going to assign the Mk 3 to Livermore and the Mk 18 to Los Alamos.[36]

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[35]N. E. Bradbury to Dr. Michael M. May, DIR-2032 (SRD) (June 1, 1966), 2 pp., A99-019, 186-2.
[36]USAEC Delmar L. Crowson, Wash., D.C. to RUWPQA/USAEC L. P. Gise, Albuq., N. Mex., et. al. (SRD) (June 23, 1966), 3 pp., A99-019, 182-1.

Newtonian telescope; a beam splitter formed images for two television cameras. Proximity focus image intensifiers excluded gamma-produced light before neutron arrival and debris-produced light thereafter. The instrument package was protected by kinking the path from the device as much as possible and placing baffles along the optical path pipe to prevent neutrons and gamma rays from reaching the television package."[97] The TV Pinex technique had first been used by the Los Alamos group on the Rickey test fired in 1968. TRAX was a time-resolved asymmetry type experiment. In this type of diagnostic an array of detectors viewed the boost region through collimators to give both a time and energy resolved measurement of the 14-MeV neutron production in the boost region. This technique was first used on Door Mist in 1967.[98]

(b)(3)

[97] R. W. Peterson to Doug Venable, WPC-O, Subject: "List of J-Division Diagnostics," J-DOT – JRPO-77-4 (SRD) (August 15, 1977), pp. 1–2, A86-049, 1-6.

Vander Maat discussed his calculations vs the then available diagnostic data during the January 28, 1970, meeting of the TWG. If he used one type of input in his secondary calculations, he obtained a number similar to the fission but not the fuel yield; if he used a different input, he obtained a number similar to the fuel but not the fission yield. Thus, no matter what his input parameters were, he could not get an output consistent with the observed data. The meeting minutes state his conclusions, "The fuel results indicate that either we do not know how to calculate fusion and fission or we do not know how to interpret the radiochemical results."[104] This problem, as will be noted in the following paragraphs, would continue to bother ~~the design team.~~

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[104]"Theoretical Weapons Group, Minutes of the 135th Meeting," TWG-141 (SRD) (January 28, 1970), p. 4, 18, A99-019, 87-15.

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(b)(3)

b. Preparations and Test

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Diagnostics were to be alpha, time-interval, television-time-integrated Pinex, and radiochemistry.

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The WX-3 and the J-Division work programs were on schedule. A tower would be used for the rack.[229]

(b)(3)

[229] "Toggle," JOHO-73-8 (SRD) (January 17, 1973), pp. 1–2, B11, Drawer 109, Folder 2 of 3.

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Indeed, the J-Division schedule slipped, but not by a full month.

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c. **MacDougall's Response**

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Pinex pictures had been obtained. The event had been completely contained; detectors, located 557 ft below the surface, had shown no above-background radiation or excessive pressures in their readings.[233]

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[233]Univ. of Calif., Los Alamos Sci. Lab., D. P. MacDougall, Los Alamos, N.M. to BY3/Captain Wayne L. Beech,

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d. Results and Implications

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Good data had been obtained from zero time until 4 μs when a short noise pattern had occurred. The data were again good from 4 to 8 μs after

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which time no further data were collected. Additional information and pictures of the Pinex images are available in the cited reference.[237]]

To conclude the data presentation at the April 18 WWG meeting, radiochemist Bryant reported the radchem results,

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[237]Leslie M. Redman, "LASL Weapons Quarterly (U), for the Period Ending March 31, 1973," Los Alamos Scientific Laboratory report LA-5330-PR (SRD) (June 1973), pp. 60–62.

(b)(3)

h. Results

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Preliminary results were again discussed during the August 15, 1973, WWG meeting. These included a presentation by Kruse of the J-14 data. The TRAX experiment had yielded gamma and neutron signals with good time resolution. Kruse presented graphs showing detector currents for gammas and neutrons. Berzins reported on the J-12 Pinex results. He included a computer analysis of the Pinex data.

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As discussed in Chapter II, the postshot report on the primary was released on March 14, 1974.

i. Considerations

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3. Reservoir Designs to Provide Minimum Helium in the Boost Gas

In a March 1969 memo, primary designer R. Canada outlined the problems that were the result of the formation of ^{3}He from the decay of the tritium used in the primary's boost gas.

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The yield of a boosted primary is degraded as tritium is converted to ^{3}He both by the loss of the source of 14-MeV neutrons and also by the decrease of the pre-boost multiplication rate caused by the high cross-section for neutron capture which is characteristic of ^{3}He." He went on to add, "In a conventional boosted single-stage device the tritium produced by ^{3}He appears too late in the bomb's explosion to contribute to the yield, and the temperature does not get high enough to produce significant $^{3}He + D$ fusion."[293]

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[293]R. Canada to Distribution, Subject: "^{3}He in Weapons," W-4-2518 (SRD) (March 10, 1969), 5 pp., A99-019, 199-13.

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C. Vulnerability

1. Considerations

As the USSR began to develop missiles that carried nuclear weapons, military planners in the United States became concerned that these types of weapons could be used as defense weapons against incoming nuclear-armed missiles from the United States. The question then arose as to how to "harden" the U.S. reentry vehicles and warheads to minimize the impact of this type of Soviet defense.

In addition, it became technically possible in the United States to have one missile carry more than one warhead. As these warheads were released and detonated over a target(s), and if the offensive warheads were detonated too close together during a similar time period, the radiation released from one would affect the others. Again, there was the question of how best to deploy these types of warheads and how to "harden" each warhead from the effects of the others (fratricide).

In response to these problems, scientists in the U.S. weapon complex developed special materials and engineering features designed to minimize the damage (both from radiation and from the shock and heat produced by the interaction of radiation with materials) to a nuclear warhead

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~~It was necessary to test~~ these designs and materials to see if they met the design objectives. The tests included field-type tests and tests at NTS. In addition, computer codes were developed, based on experimental data, to predict the behavior of components under adverse conditions.

Several types of field tests were employed. In one type of test, shocks were sent into the special materials to study their behavior. Other tests measured the effects of high temperature and similar adverse environments. In another type of test, radiation from a radioactive source, an accelerator, critical assembly, or reactor was used to expose the device to neutrons or x-rays. The type and amount of radiation that could be delivered was dependent upon the irradiating source. These field tests were never able to duplicate an actual exposure environment during deployment.

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The most complex and expensive tests employed were the NTS-type tests. These tests were used to mock-up, in so far as possible, the actual conditions that a warhead might be subjected to. In the following section these vulnerability tests will be briefly described in terms of the specific tests that were relevant to the pre-Phase 3 development of the XW76.

2. NTS Vulnerability Tests

a. Description

NTS vulnerability tests were "effects" tests where the output (neutrons/x-rays) from a detonated nuclear device was used to determine how various weapons, weapon materials, and engineering features would respond should they encounter a hostile environment. This environment might result from the nearby detonation of a nuclear ABM sent by the targeted country or from close detonation of warheads from a U.S. missile in a MIRVed type of deployment. The hostile environment might be encountered at high altitude or near the target.

In this type of NTS test, the sponsoring agency specified what type and level of radiation was required for their experiments. Participating agencies could also specify what exposure would be most useful in their experiments.

Many of the vulnerability tests were sponsored by the Department of Defense/Defense Atomic Support Agency (DOD/DASA). These tests usually had, as noted in Chapter I, double names. Some were sponsored by a weapon laboratory. The sponsoring agency's project managers decided (based on what they wanted in terms of radiation output) on a suitable device. The laboratory (Los Alamos or Livermore) that had designed this device was then asked to provide the device and to assume responsibility for emplacement and detonation of the device. In general, this device was usually a design that had already undergone a previous test(s) where the output radiation had already been determined. If a tested device were not available, a preliminary test to determine specific output might take place at NTS. In addition to supplying and detonating the device, the scientists at the specified laboratory were also responsible for the device diagnostics. In addition, certain diagnostics, for example seismic yield, were done on a routine basis by outside agencies.

Once the nuclear device with its known output had been specified, suitable stations at various distances from the device were set up in the facility in which the experiment was to take place. (Because of the layout required, vulnerability tests were usually done in tunnels at NTS.) The necessary shielding was installed. Instruments to measure the flux of the radiation falling on the samples to be tested were designed, built, and installed. The pieces of equipment or samples for which exposure data were desired were inserted at the specified locations. Special closure assemblies, used to close off the affected region and in theory, prevent bomb debris from spreading into the main tunnel/environment, were designed and installed.

The test configuration with its tunnels, test stations, access holes, and other required facilities could be extremely complex.

(b)(3) The zero room housed the detonated device, firing stand, firing and diagnostics equipment, and front-end closures.

(b)(3) Another line of slight extended from the zero room into an alcove designated "M." The line of sight for the major experimental areas was constructed in a main

drift 925 ft in length. A further 30-foot extension consisting of an arched tunnel housed alcove L. As shown in Figure IV-4, several shafts were used to access the various areas.[333]

John Hopkins, former Test-Division leader, has commented that each layout for a vulnerability test was different. However, all were major efforts in terms of construction and instrumentation.

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CHAPTER V. WEAPON PROGRAMS AND CHANGES IN THE STOCKPILE: 1965–MAY 1973

A. Phase 3 Programs at Los Alamos

1. Assignments

a. Phase 3 Programs Entering the Stockpile

During the period 1965–May 1973, the Los Alamos Scientific Laboratory weapon development and design group members were responsible for several Phase 3 weapon programs. [The Phase sequence for weapon programs is noted in Chapter I.] For those weapons that entered the stockpile, the specific weapon program, the date of the Phase 3 award, and the date of the attainment of Phase 6 are as follows:[1]

Weapon Program	Phase 3	Phase 6
B61 Mod 0	June 1963	January 1967
B61 Mod 1		February 1969
B61 Mod 2	August 1971	June 1975
B61 Mod 3	March 1972	October 1979
*W66**	*January 1968*	*October 1974*
W69	January 1967	February 1972
W72	May 1969	September 1970
* Never deployed to the field[2]		

b. Canceled Phase 3 Assignments

In addition to those weapon programs assigned to Los Alamos that were in or went into Phase 3 during the 1965 to 1973 period and entered the stockpile, several Phase 3 programs were assigned to Los Alamos but were later canceled. These were the XW64, XW67, XW73, and XW74.[3]

c. Discussion

The Phase 3 weapon programs under development at Los Alamos from 1965 through May 1973 will be discussed in the following sections. Each section will cover a specific weapon.

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[1]"FY 1994 Annual Weapons Program Report," DOE Albuquerque Operations Office report (SRD) (October 1, 1994), pp. 25–26, 301, 309, 326.

[2]"FY 1994 Annual Weapons Program Report," DOE Albuquerque Operations Office report (SRD) (October 1, 1994), p. 301.

[3]Betty L. Perkins, "Why Nougat? (U)," Los Alamos National Laboratory report LA-12950-H (SRD) (November 1, 1995), p. A-3.

2. Weapon Programs

a. B61

While the Phase 3 assignment for the B61 Mod 0 was received by the Los Alamos Scientific Laboratory in 1963, the Los Alamos weapon groups were going to find that they would have an extended development program for this weapon. The B61 would go through many models and deployment objectives over a period of many years. Several Mods of this bomb, in modified designs from the ones that were first developed, are still in the U.S. nuclear weapon stockpile.

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The B61 Mod 0, 2, and 5 bombs would be carried by U.S. Navy A-6E and F/A-18A/C/D aircraft. These bombs would also be carried by U.S. Air Force F-16 A/B/C/D and F-111 D/E/F aircraft. The later Mod 3, 4, and 10 variations would be carried by U.S. Air Force F-16 A/B/C/D and F-111 D/E/F aircraft as well as F117-A aircraft. The Mod 3, 4, and 10 bombs would also be carried on NATO F-16 A/B aircraft and on Tornado aircraft. A recent version (Mod 7) is carried on the Air Force B-2A and B52-H. As the different Mods were introduced into the stockpile, many additional safety features would be included. The early Mod 0-Mod 2 designs discussed in this section have been retired from the stockpile or converted.[4]

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The B61 Mod 0 and Mod 1 weighed 715 lb and had a diameter of 13.3 inches and a length of 141.6 inches. The B61 Mod 0 first entered the stockpile in January 1967.

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[4]"FY 1994 Annual Weapons Program Report," DOE Albuquerque Operations Office report (SRD) (October 1, 1994), pp. 25, 29.

b. XW64

In May 1964, the Military Characteristics for nuclear warheads for the Lance Missile system were issued. This missile was to be a surface-to-surface missile for use by the Army. Both Los Alamos and Livermore submitted proposals for this warhead. As it would turn out, both Laboratories would initially receive the authorization to proceed. The XW64 was the nomenclature given to the Los Alamos design; XW63 was the nomenclature given to the Livermore design.

Los Alamos received the authorization to proceed with the development of the XW64 on July 20, 1964. (b)(3)

However, the initial authorization was soon withdrawn. Attempts were made by the Los Alamos management in 1966 to have the program reactivated.[77] But neither the XW63 nor the XW64 was ever produced.

The final warhead, that provided a nuclear capability for the Army's surface-launched guided missile (MGM-52C) known as Lance, was the W70. The Phase 3 assignment for the W70 warhead was given to Livermore in April 1969

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c. W66

The W66 was a two-stage thermonuclear warhead designed for use on the Sprint missile. This missile was a short-range, low-altitude, quick reaction intercept missile. Therefore, the missile had high launching and maneuvering accelerations and a very short reaction time between launching and the firing of the warhead.

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The Sprint missile/warhead was part of the Safeguard weapon system.

The AEC laboratories originally received the Phase 3 authorization for the development of the warhead for the Sprint missile system in September 1965.

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[77]N. E. Bradbury, Los Alamos Scientific Lab., Los Alamos, N.M. to Brig. Gen. Delmar L. Crowson, DMA, USAEC, Wash., D. C., DIR-2017 (CRD) (February 14, 1966), p. 1. A99-019. 217-7.

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However, these tests were very useful in guiding the design of the XW74.[427]

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[429]R. K. Osborne and M. T. Thieme, "Theoretical Design of Implosion Weapons, 1959-1980 (U)," *Defense Research Review*. UCRL 53880-4-2 (SRD) (July 1992). p. 72.

(b)(3)

The fourth quarter report from W-Division for 1970 notes that the Poseidon C3 Alternate Front End Study had been completed by Lockheed Missiles and Space Company. The purpose of the study had been to identify the preferred design for a new reentry body payload, called the *Mk 1 Prime, for the Poseidon missile in the event that the Mk 3 MIRV system could not be deployed as planned.*

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The total warhead weight was 680 lb.[446]

Improved Spartan

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Phase 6 for the W71 would not be achieved until October 1974. (The weapon would be placed in the inactive stockpile in October 1976.[447])

In a February 24, 1970, letter to Chairman of the AEC, Glenn T. Seaborg, John S. Foster, Director of Defense Research and Engineering wrote, "The Department of Defense desires to determine the feasibility of a nuclear warhead for the Improved SPARTAN missile warhead section....The Improved SPARTAN missile is a sub-system of the SAFEGUARD ballistic missile defense system and is being designed to provide a long-range intercept capability in the exoatmosphere against ICBM and SLBM reentry vehicles (RVs), long-range intercept capability in the atmosphere against depressed trajectory RVs, a capability to intercept penetration-aided RVs, an endo- and exoatmospheric intercept capability against FOBS [Fractional Orbital Bombardment System], and an intercept capability against satellites (but only within missile performance limitations)." [Author's note: Wow, what an assignment!] Foster noted that the presently planned improved Spartan missile would use the Spartan missile's first and second stages while incorporating a new third stage(

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An effort through Phase 2 was requested for this improved Spartan missile.[448]

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The Laboratory's quarterly report for January–March 1970 states, "Though there are many system parameters as yet unresolved, the AEC has received a formal request to participate in the Phase 2 Feasibility study of warhead designs for the Modified Spartan missile system."

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[446]"Program Status Weapons Research and Development, October-December 1970 (U)," Los Alamos Scientific Laboratory report LA-4614-MS (SRD) (February 1971), p. 42. "W-Division Quarterly Status Report, October 1, 1970 through December 31, 1970," W-2301 (SRD) (January 15, 1971), p. 66, A86-016, 242-15.

[447]"FY 1994 Annual Weapons Program Report," DOE Operation Office report (SRD) (October 1, 1994), pp. 318–322.

[448]John S. Foster, Jr. to Honorable Glenn T. Seaborg (SRD) (February 24, 1970), 5 pp., A99-019, 186-10.

A TWX dated September 15, 1970, pointed out that the system cost for the Minuteman III and MIRV was 2.2 billion. The projected cost for the Mk 19 was approximately 130 million. Thus. the R&D cost for the Mk 19 was 5% of the total system costs.[467]

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FUFO

During 1970, the DOD guidance placed emphasis upon a new FUFO bomb

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SABMIS

There also continued to be an interest in a Sea-Based Anti-Ballistic Missile Intercept System. It was reported that development schedules for this system were such that tests of the warheads themselves would not be scheduled for FY 1971.

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[467]D. W. Bergen, Los Alamos Scientific Laboratory, Los Alamos, N.M. to C. I. Hudson, University of California, Lawrence Radiation Laboratory (SRD) (September 15, 1970), p. 3, A99-019, 188-4.

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/It is a step in

~~the development~~ of a warhead for the Modified SPARTAN."[493]

Hardsite Defense (SPRINT II)

The third quarter report for 1971 from the Laboratory notes that a new component of the Safeguard ABM system, called "Hardsite Defense" (HSD), was to be implemented. It was reported, "HSD consists of an autonomous module for close-in, low-altitude intercept (≈10,000 to 30,000 ft) and is based upon three radar/data-processor units located about 10 nautical miles apart. The module will have six or seven firing sites containing about 100 modified Sprint interceptors to defend approximately 21 silos." The new interceptor was to be known as Sprint II; the planned readiness date was July 1977.

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/An AEC/DOD Joint Working Group had been set up to provide an alternative that used less tritium. A number of proposals had been suggested,

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[493]D. P. MacDougall to Major General E. B. Giller, USAF, ADW-158 (SRD) (November 5, 1971), p. 4, A99-019, 258-28.

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High-Yield Warheads

Harold Agnew in a letter to Assistant General Manager for Military Application, Major General Edward B. Giller, stated that the country should consider what would happen if there were to be a ban on the use of MIRV and at the same time there was a ban on testing. Agnew recommended that the country should develop and test the highest possible yield warhead that could be carried as a single [warhead] on the Poseidon. He felt that the same should be done for the Minuteman and, if the Titan were kept in service, a high-yield warhead should also be developed for this application. He noted, "...we won't be carrying out our responsibility to the U.S. if we don't do these nuclear developments."[510]

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[510]H. M. Agnew to Major General Edward B. Giller, DIR-2250 (SRD) (July 6, 1971), 2 pp., A99-019, 269-3.

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High-Yield Bomb (HYB), Formerly FUFO

In a February 28, 1972, memo, D. P. MacDougall reported that Giller in a January 20, 1972, document had indicated that he anticipated that a Phase 3 request might be initiated in the FY 1972–1974 time period for a High-Yield Bomb (HYB) (formerly FUFO).[543]

The second quarter report from the Laboratory for 1972 includes, as part of the High-Yield Bomb program, what was to become a very important project for the Laboratory. The report states, "The explosive TATB (1,3,5-triamino-2,4,6-trinitrobenzene) was first described in 1888, but was recognized as a very interesting heat-resistant explosive only in the 1950s. At that time the Naval Ordnance Laboratory reported briefly on its properties and presented a reasonable synthesis." The report notes that this material had a great insensitivity to impact and friction and an explosive power superior to that of other heat-resistant explosives,

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The third quarter report for 1972 states, "We have continued experiments to characterize the 90/10 TATB-Kel-F 800 material discussed last quarter, hampered somewhat by our limited stock of material. First deliveries of TATB from Pantex are expected soon to alleviate this shortage."[545]

The third quarter report also states, "The USAF and USN have studied the 'Final Report of the Phase 2 Feasibility Study of the High Yield Bomb,' dated March 21, 1972, ...and agree that it is technically feasible to develop a high-yield bomb that meets the stated requirements, with a minimum 4-yr development time, and that no bombs that meet the requirements of the HYB are currently available or in production. Subsequently, the Services have requested a Phase 3 Development Engineering program for the HYB.

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[543]D. P. MacDougall to Distribution, Subject: "Program Planning," ADW-204 (SRD) (February 28, 1972), 3 pp., B11. Drawer 49. Folder 1 of 5.

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[545]Leslie M. Redman and Cecil C. Carnes, Jr., "Quarterly Status Report on Weapons Research and Development for the Period Ending September 30, 1972 (U)," Los Alamos Scientific Laboratory report LA-5130-PR (SRD) (January 1973), pp. 53–54.

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The Laboratory's fourth quarter report for 1972 announced that a new full-fuzing-option (FUFO) bomb program had been requested. (This program took the place of the high-yield bomb program.) The bomb size was limited to a maximum of 18-in. diameter, 145-in. length, and a 2,400-lb weight. It was to have full-fuzing options and improved safety characteristics. It would be for delivery by both strategic and tactical aircraft.

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This new FUFO bomb program was a result of the review of the March 21, 1972, Phase 2 Feasibility Study of the High-Yield Bomb and the decision that certain aspects of the feasibility study should be expanded before a final decision was made on a Phase 3 development. In terms of design considerations, for the LASL proposals it was noted that, for safety reasons, it was desirable that the bomb incorporate use of the new insensitive explosive

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B. Mark 400 Program

1. Livermore vs Los Alamos: The Navy's Submarine-Launched Ballistic Missile (SLBM) Warheads—W47, W58, and W68

Navy planners and others realized that a ballistic missile outfitted with a nuclear warhead that could be launched from a nuclear submarine presented a weapon system that could be highly effective as a deterrent. This concept was placed into practice with the development of the first SLBM nuclear warhead: designated the W47. This warhead was designed for use with the Navy's Polaris A-1 and the Polaris A-2. It first entered the stockpile in June 1960. There were several modifications made in the warhead during its stockpile lifetime. The next warhead placed into deployment on a submarine-launched ballistic missile was the W58. This was used in the Mark 2 reentry system fitted on the Polaris A-3; this missile could carry three warheads. The weapon development groups at Livermore were responsible for these early warheads. The Lockheed Missile and Space Company (LMSC) carried the major responsibility for the carrier of the warhead(s). A detailed account of the development of the W47 and W58 is given in LA-13755-H (SRD). During the development of these systems, a close relationship was established between Livermore, Lockheed, and the Navy.

The early Livermore–Lockheed–Navy association was a close one. However, the administration at Los Alamos very much wanted to be included in this group. One way to get a foot in the door was to have Los Alamos people present at planning meetings. [Author's note: It should be noted that as an exception Ralph Williamson from T-2 participated in the group known as the Polaris Ad Hoc Group for Long Range Research and Development. He appears to have attended the meeting held on April 29–30, 1965, at the Naval Research facilities in Washington.[106] Although documentation is lacking, he probably attended similar meetings held at other times.]

In the fall of 1965, Al Bridges from Kaman Nuclear visited Los Alamos. At that time a request was made to him to have representatives from Los Alamos participate in the Navy's planning meetings. [Author's note: The administration at Los Alamos must have known that the Navy was interested in developing a new ballistic missile/submarine system to be called Poseidon.] On December 6, 1965, the Chief of Naval Operations requested that the AEC laboratories be authorized to cooperate with the Navy in joint conceptual studies leading to the determination of optimum parameters for various components of the Poseidon missile. This request in turn led to the inclusion of Los Alamos in a memo from Brigadier General Delmar L. Crowson, Director of Military Application. Crowson requested that the Sandia Corporation, the Los Alamos Scientific Laboratory, and the Lawrence Radiation Laboratory participate with the Navy in these requested conceptual studies.[107]

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[106]Chairman, Polaris Ad Hoc Group for Long Range Research and Development (PLRRD) to Distribution, Subject: "PLRRD Meeting 29-30 April 1965," SPOO110/RHY:md 3900 (U) (March 31, 1965), 1 p., Ralph Williamson papers, A86-049, 1-1.

[107]Brigadier General Delmar L. Crowson to L. P. Gise, Subject: "Joint AEC/Navy Conceptual Studies for Optimization of Poseidon Missile System," (SRD) (December 22, 1965), 1 p. and enclosure, A99-019, 217-15.

and firing (AF&F) system incorporating component technology developed during the Mk 3 program and other recent advanced development programs could be supplied.[123]]

The second meeting of the Re-entry Committee of the Fleet Ballistic Missile Steering Task Group was held on January 28, 1970, at the Naval Ordnance Laboratory (NOL) in Silver Spring, Maryland. It was reported that performance goals of the new ships to replace the Polaris/Poseidon ships were beginning to be outlined. The new ships would be on patrol 80% of the time with an 83-day patrol period. They would have a 7–15 db noise level below the present ships. They would include a long-life nuclear reactor. They would be designed with a collapse depth of 1,350 feet. For the missile launcher system, the tube dimensions being considered were a diameter of 115 to 135 inches and a length of 50 feet. The ships would each be capable of carrying twenty-four missiles. Each missile would have a minimum missile range of 4,500 nm. It was the missile that would be the determining factor in the size of the submarine. The missile candidates at that time ranged from the 34-foot long, 74-inch diameter C3 missile to a proposed 49-foot long 110-inch diameter missile. Several ship designs were under consideration, including a single hull vs several types of double hull configurations. Decisions still to be made included the number of missiles a ship should carry, launch tube diameter, launch conditions, number of people on each sub, shipboard environment requirements, ship/missile accuracy, and maintenance. The schedule then under consideration called for a nominal number of new-class ships by FY 1978. In terms of improvement in the warhead, it was indicated that with a suitable timeframe available for development, an explosive electric generator could be manufactured reliably. This type of generator would reduce the need for high currents for ignition. Improvements in CEP [circular error probability] were also possible. It was also reported that by using large reentry angles, high ballistic coefficients, and low radar cross sections, the offense could reduce the defense's engagement time. Hardening options were also presented at the meeting. It was recommended that the Navy spend "time and effort pursuing hardened system designs."[124]

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Although not part of the Mk 400 program, it will be noted that in the summer of 1970, the Navy was also interested in a program called CAFE. This stood for C-3, Alternate, Front End.

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[Author's note: There was concern at that time that, due to political considerations, that the use of the Mk 3/W68 (MIRV) might be restricted or abolished.] The first CAFE Reentry Interchange Committee Meeting took place on July 15, 1970. The LASL/SLA laboratories submitted data for the CAFE study in a document dated August 7, 1970. The principal warhead proposal from LASL was the use of a W67-like device. It was noted, "Many of the development tests, up to flight tests, have been completed for this device; construction drawings are available." Use of a 16M type of device was also

[123]"LASL/SLA Revised Data Package for ULMS (Undersea Long Range Missile System) Study," W-9-754 (SRD) (September 1, 1970), 12 pp., A99-019, 214-15.

[124]"Minutes of the Second Re-entry Committee of the Fleet Ballistic Missile Steering Task Group Meeting (U)," Kaman Nuclear report KN-70-68 (R) (SRD) (February 7, 1970), 178 pp., A99-019, 163-6.

(b)(3)

boat was to be six years after the IOC of the missile.

(b)(3)

The Packard memo had also asked the Navy to consider an optional RB that had a maneuvering capability.[147]

(b)(3)

[Author's note: This was good news for the Los Alamos group. It appeared that a Los Alamos proposal was being used in the RB design studies.]

There was also the Small Evader Experiment (SEE). During the October 20, 1971, meeting of the WWG, Gillespie informed the attendees that SEE was a minimum-weight, minimum-size maneuvering warhead for Poseidon. General Electric personnel planned to have the SEE project in a study phase through December; flight tests were to begin as quickly as possible after that. (b)(3) Gillespie reported that the LASL group felt that they had a better design for this application. Gillespie also reported on the EXPO program. He noted that EXPO had, in essence, been renamed ULMS. The Phase 1 would require a new missile for the Poseidon boat; two alternative missile developments were desired.

(b)(3) /For this system, the Navy's SSPO was trying to avoid the usual Phase 2 program by repackaging the W68 as the warhead. The second alternative missile development would be concerned with a missile that would carry a maneuvering reentry system similar to SEE.[149]

On October 20, 1971, a meeting was held at the Sunnyvale offices of LMSC. T. P. Seitz and F. B. Baker from W-9 were the Los Alamos attendees. Their trip report indicates that the discussions centered on the status of the ULMS/

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The reentry body was limited to a weight of 170 pounds, a length of 65 inches, and a diameter of 15.8 inches.

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[147]C. M. Gillespie, W-9 to Distribution, Subject: "Imminent Phase 2 on EXPO-ULMS," W-9-1185 (SRD) (September 23, 1971), 1 p., A99-019, 214-15.

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[149]"Weapons Working Group, Minutes of the 234th Meeting," WWG-234 (SRD) (October 20, 1972), pp. 10–12, A99-019, 92-18.

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fabrication facilities." (b)(3)
Additional information is available in the cited reference.[196]

(b)(3)

The final draft of the Phase 2 feasibility study report was also released in the summer of 1972. (b)(3) In the Los Alamos files the draft study report carries a date, made in pencil, of July 1, 1972. The cover sheet for the document carries a date of June 26, 1972. As previously noted, during the second meeting of the Mk 400 mini-POM group held on June 28, 1972, it had been announced that the Phase 2 report had been approved.]

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The final yield of the new warhead had not yet been specified.

(b)(3)

In the

[196]"Report of Impact and Capabilities Study for the Mk 400 Reentry Body for Poseidon C-4 and Trident (Previously ULMS)," Draft, AEC Albuquerque Operations Office report I&C No. 5-72 (SRD) (July 1, 1972), 20 pp., B11, Drawer 56, Folder 1 of 4. Also in B11, Drawer 56, Folder 3 of 4.

(b)(3)

16-inch base diameter in the RB. This is the base diameter used in the design of the W76.] Near the end of his trip report, Sandford included several pieces of interesting "gossip." He reported, "At DDR&E we talked to John J. Brett who seemed to react favorably to our new, higher yield proposals. At the SPO we briefed Cdr. Stinner, Mark Messerole, and Hal McMasters. They seemed relieved and/or amused that our WHs now were competitive with LLL's WHs." In addition, Sandford reported, "At DMA we briefed General Camm, Tom Clark, Col. Haidler, and several of their staff members. The briefing went very well with several pertinent questions being asked." Furthermore, Sanford reported, "The MK-400 I&C study indeed was stuck in the AEC.

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Pending resolution of this problem, the Phase 3 request cannot be sent to DMA." It was also noted in the trip report that the question of the requirements for special nuclear material had been discussed by Tom Clark. The trip report states, "The only concrete message gleaned from Clark's talk was that one or two reactor restarts at Savannah River are feasible but the AEC does not want to restart any of the Richland reactors." [203]

Despite this report from Hoyt and Sanford of the delay in the I&C study, on August 17, the AEC proposed to send the AEC Impact and Capability study to Foster at the Defense Research and Engineering, Department of Defense. As to the reactor question, the proposed cover letter for the study noted, "In addition, we believe that, while restart of up to four reactors is theoretically possible, in light of decisions which have been made in the past the restart of the two standby reactors at Savannah River would be difficult enough to achieve; the restart of additional reactors at Richland might pose intractable problems, particularly in view of current environmental concerns." The letter added, "Certain adjustments to the assumed Mk 400 delivery schedules and to the assumed base stockpile might possibly reduce the number of reactor restarts required." The letter ended by stating, "In order to meet the desired IOC date of December 1977 it will be necessary for us to receive a Phase 3 decision by the end of August so that the AEC can arrange for the necessary capital funding."[204]

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He included attachments of the vufoils that had been used in the August 7 briefing given to Assistant DDR&E Director John J. Brett.[205]

(b)(3)

[203]T. A. Sandford to D. P. MacDougall, ADW, Subject: "Mk-400 and High Yield Bomb Briefings in Washington (U)," ADWP-1-72-19 (SRD) (August 17, 1972), 7 pp., B11, Drawer 56, Folder 3 of 4.
[204]Thomas R. Clark to J. A. Hornbeck, President, Sandia Laboratories et. al., Subject: "Mk 400 I&C Study," (SRD) (August 21, 1972), 1 p., and two attachments, B11, Drawer 56, Folder 3 of 4.
[205]T. A. Sandford to Dr. John S. Foster, Jr., Subject: "LASL/SLA MK-400 Briefing (U)," ADWP-1-72-20 (SRD) (August 21, 1972), 8 pp., B11, Drawer 56, Folder 3 of 4.

reductions associated with nose radii greater than optimum, they were considering a self-deploying aerospike on the nose fairing of the C4 missile.

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The flight test program was also discussed. The AF&F sequence of the Mk 400 was also reviewed. There were several presentations made during the meeting on the possible types of overcoats that might be used to reduce vulnerability.[214]

The quarterly progress report from the Laboratory for the period ending September 30, 1972, noted that for the Mk 400 there had not been a Phase 1 program. Phase 2 had been informally started in November 1971; however, the formal direction from DMA to participate in the Phase 2 had not been received until February 3, 1972. The LASL Phase 2 data package had been submitted on February 28, 1972. Although the final Phase 2-study report had been dated July 1, 1972, the report had not been formally distributed by SSPO until September 1972. In August 1972, the LASL groups had presented to SSPO, DDR&E, and DMA representatives the new design improvements that had been made. In turn, new reentry-body weights for the new warhead proposals had been developed.[215]

The Trident system was discussed at length during the October 5, 1972, meeting of the Theoretical Weapons Group (TWG). Gillespie stated that the purpose of the Fleet Ballistic Missile System was to provide deterrence through an invulnerable force capable of inflicting unacceptable damage to the Soviet urban/industrial complex. Gillespie noted that by treaty the United States was limited to 44 submarines. As of October 1972, the U.S. had 10 Polaris submarines that carried the A3 missile. (b)(3)

There were 31 Poseidon submarines that carried the C3 missile (b)(3) The new Trident would carry the C4 missile.

(b)(3) Trident had an IOC of 1978. It was twice as large as the Poseidon boat and could carry the larger D5 missile.

(b)(3)

Gillespie also noted the importance of minimum weight in terms of maximum range. Gillespie then discussed, assuming that LASL was assigned the Phase 3 in January 1973, the future test program

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Several additional tests would be necessary before a final weaponized design was achieved. The minutes of the meeting state, "In closing, Gillespie outlined the reasons for supporting LASL as the recipient of the MK 400 Phase 3 in terms of past experience, the present LASL program and the availability of program support

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[214]F. W. Kramer, K. F. Famularo, J. C. Fuller, C. M. Gillespie and T. A. Sandford to Distribution, Subject: "Mark 400 Mini-POM, September 27-28, 1972 (U)," ADWP-1-72-52 (SRD) (October 12, 1972), 4 pp., B11, Drawer 56, Folder 1 of 4.

[215]Leslie M. Redman and Cecil C. Carnes, Jr., "LASL Weapons Quarterly (U), for the Period Ending September 30, 1972," Los Alamos Scientific Laboratory report LA-5130-PR (SRD) (January 1972), p. 68.

(b)(3)

The second quarter report from the Laboratory for 1973 noted that the Mk 400 was the reentry body for the C4 Trident missile; it was being designed for use on the new Trident submarine

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. (Phase 3 development of the W76 WH for the Mk 4 RB was awarded to LASL and SLA on April 27, 1973.)"[264]

11. Significance

It had been a long and at times bitter fight. But the laboratory at Los Alamos had won the long desired strategic warhead assignment. However, the laboratory staff was now under extreme pressure to develop and design a warhead that would (1) meet the yield requirement, (2) meet the size and weight requirements, (3) achieve the vulnerability and safety requirements, and (4) at the same time satisfy the minimum number of NTS development tests, the strict time restraints, as well as the budget limits that had been placed on weapon development.

It was never envisioned that the in the year 2003 planning would be in progress to retain the W76 in the U.S. stockpile.

C. Harold Agnew

1. Proponent

While the entire staff at Los Alamos worked hard to obtain the Phase 3 for the Mk 400, one of the chief proponents for this award was Harold Agnew. (From the information given in Chapter I, the reader will recall that Agnew became Laboratory Director in 1970.) Agnew felt that there were many reasons why the award should go to Los Alamos

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[264]Leslie M. Redman, "LASL Weapons Quarterly (U), for the Period Ending June 30, 1973," Los Alamos Scientific Laboratory report LA-5401-PR (SRD) (September 1973), p. 58.

7. Yield: The Confetti Argument

Agnew felt that the yield of the W68 was too low to be really effective. In addition, in terms of the overall total yield available from all the W68 warheads, the W68 design was very costly in terms of the amount of required special nuclear materials.

In an April 1972 TWX to Assistant Director for Safety and Liaison (Division of Military Application) Colonel Robert T. Duff, Agnew reported that he was worried about maintaining the U.S. nuclear deterrent. Agnew noted, "It occurs to me that as we go to lower and lower yields in our strategic missile warheads and the Soviet Union builds up a better and better civil defense position, the reality of this deterrent may become questionable.

(b)(3)

If the Soviet leadership believes this, then our strategic deterrent will have lost a good deal of its force. If our MIRV trend continues we'll be threatening to throw confetti at a potential aggressor. Confetti has high penetration and survivability but little deterrent power."[281]

In a letter dated October 10, 1972, to Giller, at that time Assistant General Manager for National Security, Agnew again noted several reasons why low yield warheads might not be the best solution for maximizing the deterrence capability of the stockpile. He reported that considering the number of required submarines and the low efficiency in their use of special nuclear material, the low-yield warheads were not very cost effective. Moreover, Agnew pointed out that for the Hiroshima device, the effects on Hiroshima in terms of loss of substantial buildings and the people in them "wasn't all that impressive." In terms of loss of life, the USSR had lost more than ten million people in WWII. Although the Soviets had an extensive civil-defense network in place, even if that did not work to reduce loss of civilian lives, the Soviets might not mind losing a few people. Agnew wrote, "Again, to me, to continue to increase warhead numbers at the cost of a decrease in yield per warhead could eventually lead to no deterrence in the minds of those we hope to deter." Agnew stated, "I feel very strongly that we should endeavor to convince the DoD that what they should have on the next round is a mix of yields.

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8. Capability

Agnew in his August 10, 1972, letter to Camm pointed out that the Los Alamos group had been developing suitable technology applicable to the new strategic missile warheads. He wrote, "In summary then, we have been working very hard to provide the very latest technology in warhead designs incorporating the most advanced minimum weight hardening techniques to provide an optimum warhead for the next round of strategic missile warheads. In fact, our work has been of such outstanding quality that we have been invited by Admiral Levering Smith to

[281]H. M. Agnew, University of California, Los Alamos Scientific Laboratory, Los Alamos, N.M. to BY3/Colonel Robert T. Duff, USAF, Assistant Director for Safety and Liaison, Division of Military Application USAEC, Wash., D.C. (SRD) (April 14, 1972), pp. 1–2, B11, Drawer 56, Folder 1 of 4.

(b)(3)

join his Steering Task Group for the FBM Weapon System Program in anticipation of our supplying TRIDENT with its warhead."[283]

Agnew felt that the LASL group had had extensive experience in the areas of vulnerability, hardening, and RV/warhead integration. Again, in a letter to Camm dated September 11, 1972, Agnew wrote, "Also, our in-house work and underground testing program in the vulnerability and hardening area have made a significant contribution to the nation's overall capability in this area." He also noted, "One unique advantage we have is that while we have a solid background of experience in reentry system design we are not tied to our past achievements and thereby inhibited in our approach to new designs."[284] In his November 27, 1972, letter to Camm, Agnew gave examples of how the LASL team had been the leader in several aspects of the vulnerability program.

(b)(3)

This experience had been demonstrated in the successful Mk 18 and Mk 400 programs. With money very tight and the need to limit the expense of testing at NTS, the LASL team was in the best position to develop the Mk 400 warhead with a minimum number of tests. Agnew told Camm, "Once the Phase 3 has been awarded, we will design a package in which both the primary and secondary are so configured as to provide the best possible warhead to satisfy the specific DoD requirements."[286]

9. Promise of the Next Strategic Missile Warhead

In his August 10, 1972, letter to Camm in which Agnew discussed the history of previous weapon assignments, Agnew noted that at the time of the Mk 3/W68 warhead assignment to Livermore the Los Alamos group had been promised the development responsibility "for the next strategic missile warhead, whatever it might be..."[287]

In a letter dated September 11, 1972, to Camm, Agnew again reminded Camm that LASL had been told that they would receive development responsibility for the next strategic reentry system. To meet this obligation, the members of the LASL weapon groups had been developing and testing warheads for the Mk 19, Mk 18, ABC, and Mk 400 programs. This work had resulted in the Laboratory being very involved in these types of systems. (b)(3)

Agnew reported, "These two tests cover the spectrum of possible secondary designs for the MK 400." Agnew also noted that the design of a suitable primary for the Mk 400 program was underway. He concluded his September 11 letter by stating "We feel

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[283]H. M. Agnew to Major General Frank A. Camm, DIR-2292 (SRD) (August 10, 1972), 7 pp., B11, Drawer 56, Folder 1 of 4

[284]H. M. Agnew to Major General Frank A. Camm, DIR-2293 (SRD) (September 11, 1972), 3 pp., B11, Drawer 56, Folder 1 of 4.

(b)(3)

[286]H. M. Agnew to Major General F. A. Camm, DIR-2296 (SRD) (November 27, 1972), 7 pp., B11, Drawer 56, Folder 1 of 4.

[287]H. M. Agnew to Major General Frank A. Camm, DIR-2292 (SRD) (August 10, 1972), p. 4, B11, Drawer 56, Folder 1 of 4.

that our past experience with Mk 18 and ABC, together with our current Mk 400 efforts, will enable us to continue this [successful effort] for the Mk 400 warhead."[288]

10. Morale

Agnew was fearful concerning the effect that an award of the Phase 3, Mk 400 warhead to Livermore might have on Los Alamos weapon personnel. Agnew in his November 27, 1972, letter to Camm noted, "After having had the vision to work in this field and having been extremely successful, not to receive this assignment would have a very severe impact on our staff morale."[289]

[288]H. M. Agnew to Major General Frank A. Camm, DIR-2293 (SRD) (September 11, 1972), 3 pp., B11, Drawer 56, Folder 1 of 4.
[289]H. M. Agnew to Major General F. A. Camm, DIR-2296 (SRD) (November 27, 1972), p. 7, B11, Drawer 56, Folder 1 of 4.

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PREFACE

This report is one in a CNSS series that surveys the development of nuclear weapons over the past forty-five years. The unifying themes throughout the series are the technical advances and failures associated with new weapon systems, and the creation of the stockpile.

Authors, titles, and report numbers are listed below.

William G. Davey, *Free-Fall Nuclear Bombs in the U.S. Stockpile (U)*, LA-11397

William G. Davey, *Nuclear Tests Related to Stockpiled Weapons Development (U)*, LA-11402

Lawrence S. Germain, *A Brief History of the First Efforts of the Livermore Small-Weapons Program (U)*, LA-11404

Lawrence S. Germain, *The Evolution of U.S. Nuclear Weapons Design: Trinity to King (U)*, LA-11403

Lawrence S. Germain, *A Review of the Development of Los Alamos Gnats and Tsetses before the 1958 Test Moratorium (U)*, LA-11749

Raymond Pollock, *The Evolution of the Early Thermonuclear Stockpile (U)*, LA-11748

Raymond Pollock, *A Short History of the U.S. Nuclear Stockpile 1945–1985 (U)*, LA-11401

(All reports are classified Secret Restricted Data)

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January 2, 1991

A SHORT HISTORY OF THE U.S. NUCLEAR STOCKPILE: 1945–1985 (U)

Raymond Pollock

ABSTRACT (U)

This report, one in a series concerned with the history of nuclear-weapons research and development, examines the evolution of the U. S. nuclear weapons stockpile. The report distinguishes between weapon requirements resulting from strategic and operational demands and requirements created by technological advances. The acquisition of nuclear weapons through four distinct, evolutionary phases is also reviewed.

INTRODUCTION

The purpose of this report is to identify the possible causes of significant change in the U.S. nuclear-weapons stockpile as it evolved between 1945 and 1985. While we will be concerned with the relationship between stockpile characteristics and national security policy, we concentrate on qualitative changes rather than on inventories. Our principal interest is to distinguish between weapon requirements generated by strategic and operational demands and those resulting primarily from opportunities created by the advance of technology.

As a first step, we examine the diversity of the U.S. nuclear-weapons stockpile, or more particularly, its variation over time. Figure 1 shows the total number of distinct weapon systems (as distinguished by mark number), both strategic and tactical (nonstrategic) weapons. The bar charts of Fig. 2 indicate, for the strategic category, system entries and retirements; the net of these determines the data points of Fig. 1. Figure 3 shows entries and retirements for nonstrategic systems. Examination of these figures leads to the conclusion that between 1945 and 1985 the U.S. nuclear-weapons acquisition process proceeded in four distinct phases.

In the early postwar phase (1945–1950), the stockpile remained based on the wartime Fat Man and Little Boy designs. Air Force heavy bombers provided the only delivery vehicles, and the "atomic" bomb was clearly seen as solely a strategic weapon of awesome power.

During the second phase (1950–1955), the variety of stockpiled systems grew quite rapidly, as the results of postwar R&D allowed lighter, more efficient fission bombs to be developed. New, heavier bombers made possible the entry into stockpile of the first huge, high-yield, "emergency capability" thermonuclear weapons. And the first weapons developed especially for tactical applications made their appearance.

May 1949, a study headed by Air Force Lt. General H. R. Harmon reported that even if all 133 weapons detonated on target the Soviet leadership would not be critically weakened, Soviet military ability to take selected areas of Western Europe and of the Middle East and Far East would not be seriously impaired, and Soviet industrial capacity would not be sufficiently reduced to prevent recovery. The resulting reassessment of targeting requirements led to a substantial increase in nuclear production. And in the fall of 1949, the Joint Chiefs of Staff (JCS), in conjunction with the North Atlantic Treaty committing the U. S. to European defense, tasked the Strategic Air Command with "retardation of Soviet advances in Western Europe."[1]

With General Curtis LeMay as SAC commander, and freed by the results of Sandstone from the constraints of weapons scarcity, the 60 nuclear-capable aircraft available at the end of 1948 grew to 250 by June 1950. The giant B-36 came on line in 1949, and the all-jet B-47 medium bomber would arrive in 1951. The October 1949 target annex for war plan OFFTACKLE called for attacks on 104 urban targets using 204 weapons, with 72 bombs to be held in reserve.[2] The prime objective was still disruption of the Soviet will to fight, but a number of "retardation" targets were included. By August 1950, concern over growing Soviet nuclear strength led to a further re-prioritization to assign first priority to targets supporting Soviet nuclear-delivery capability. The mission of retarding a Soviet attack in Europe was assigned second priority, and disruption of Soviet war-making capacity by attacks on electric power, atomic energy industries and liquid fuel facilities was assigned third priority. This war-fighting allocation system persisted in U. S. targeting doctrine for the next 10 years.

The move away from simple urban targeting to a more elaborate military targeting doctrine designed to meet specific military objectives was to a large degree made possible by the increasing availability of nuclear weapons, and this move, in turn, stimulated the need for new weapons.

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For the European retardation mission, which needed to deal with somewhat transitory targets, the relatively lightweight B5 tactical bomb entered stockpile in 1952. This was followed in short order by a series of new tactical weapons, including development of the Mk-9, 280-mm artillery shell; adaptation of the B5 as the W5 warhead for the Navy's Regulus and Air Force Matador cruise missiles; and development of the W7, as both bomb and warhead for the [redacted] short-range missiles, and as the first atomic demolition munition (ADM). All of these were implosion weapons, with the exception of the 280-mm artillery-fired atomic projectile (AFAP), which was gun-assembled. Interestingly, the gun-assembled B8 bomb ("Improved Little Boy") also entered stockpile in 1952 and remained for nearly 6 years.

Turning again to the strategic arena, a growing perception that many critical Soviet targets were harder than previously expected, and often covered a large area or were grouped such that "bonus" damage could be achieved with a large enough weapon, drove the quest for higher yields. Boosting was first tested in the Item shot in the 1951 Greenhouse series, and it appeared clear that megaton-yield, boosted fission weapons of reasonable weight and size could be developed. But it was also apparent that the thermonuclear weapon, first considered by Edward Teller and others in a 1942 meeting in Berkeley, would offer an economical route to very high yields if it could be made to work. And the boosted fission explosive offered the possibility of an energy source small and hot enough to provide an ideal primary stage for the practical thermonuclear concept developed by Teller and Stanislaw Ulam.

The controversy surrounding President Harry Truman's decision to go forward

Jupiter. Perhaps even more significant, the feasibility of solid-fueled missiles made the submarine a practical ballistic-missile-delivery platform, and in 1956 the Navy committed to developing Polaris.

But while the strategic forces grew and diversified, SAC doctrine of massive retaliation and emphasis on counterforce targeting, with its apparently unlimited requirements for weapons, came under steady attack within the Joint Chiefs of Staff (JCS). In the spring of 1958, a JCS majority under the leadership of Army Chief of Staff General Maxwell Taylor argued for the need to prepare for limited war. Secretary of State John Foster Dulles agreed that, with the Soviets now a major nuclear power, the doctrine of massive retaliation had outlived its usefulness. President Dwight Eisenhower, however, felt that an increase in conventional forces could be bought only at the cost of increased defense expenditures, which he would not accept, or of weakened strategic (air) forces, which he could not accept without further study. He tasked the National Security Council (NSC) to give high priority to a careful analysis of the minimum requirements for deterrence and retaliation.

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In July 1958, Admiral Arleigh Burke weighed in with the Navy's strategy to exploit the flexibility and invulnerability of the coming Polaris force. Burke argued that, while it had once made sense for the U. S. to deploy sufficient force to disarm the Soviet Union, the growing Soviet intercontinental ballistic missile (ICBM) deployment made this "blunting" or disarming mission now unworkable. In addition, the Soviets could now put at risk all U. S. land-based forces; their vulnerability invited surprise attack. The alternative was to secure the U. S. strike force by mobility and concealment, eliminating the pressure to preempt and allowing the U. S. to respond selectively in order to apply political coercion. This strategy of "finite deterrence" would require a small submarine-launched ballistic missile (SLBM) force sized for deterrence alone (i.e., the ability to destroy major urban areas).

Recognizing the Navy threat, SAC in November 1958 proposed that a U. S. Strategic Command embracing all strategic forces, including Polaris, should be formed, with the Air Force in charge. SAC would then be abolished. Burke admired the idea of dismantling SAC, but rejected the notion that anyone but sailors could operate Polaris submarines in conjunction with other naval forces. He also saw no need for any new coordination structure since Polaris would use its missiles against a (Navy-determined) target system that was generally stable..

Despite Admiral Burke's assurances, the problem of controlling and coordinating U. S. nuclear retaliation was growing more serious—even in the absence of Polaris. Thoughtful Air Force leaders believed that an overhaul of "atomic coordination machinery" was overdue. In March 1959, JCS Chairman General Nathan Twining wrote a memo to Secretary of Defense Neil McElroy addressing "Target Coordination and Associated Problems." This memo triggered no immediate action but laid the groundwork for the later formation of the Joint Strategic Target Planning Staff (JSTPS).[3]

In the last year of the Eisenhower administration, the divergence of strategic planning combined with the above considerations to create a situation that demanded resolution. President Eisenhower had grown increasingly dubious about the seemingly endless growth in Soviet targets, but, in the absence of any alternative, had acceded to SAC demands for additional weapon platforms and nuclear-weapons production. In March 1960, the Air Force Intelligence Directorate (AFID) identified [redacted] targets and projected that this total would grow to [redacted] by 1965 as the Soviets added offensive and defensive missiles. Highest priority was assigned to suppressing Soviet air defenses and stopping Soviet nuclear attack on the U. S. and its allies. Halting Soviet land and sea operations (the retardation mission) re-

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had been consolidated into the JSTPS, and the first SIOP was in effect. Nuclear support for the North Atlantic Treaty Organization (NATO) in the theater had been prepared and the weapons to implement NATO MC 14/2 were in procurement. The list of strategic weapons that entered stockpile during the last 5 years of the Eisenhower administration attests to the vigor of the nuclear production complex:

B28 (thermonuclear bomb)
B36 (thermonuclear bomb)
B39 (thermonuclear bomb)
B41 (thermonuclear bomb)
W28 (thermonuclear warhead: Hound Dog, Mace)
W39 (thermonuclear warhead: Bomarc)
W47 (thermonuclear warhead: Polaris A1, A2)
W49 (thermonuclear warhead: Thor, Jupiter, Atlas, Titan I).

The list of tactical weapons is equally impressive:

W25 (fission weapon: Genie air-to-air defense missile)
W27 (thermonuclear warhead: Regulus II)
W30 (fission warhead: Navy Talos, TADM missiles)
W31 (fission weapon: ADM.

W33 (gun-assembled fission weapon: 8-in. artillery shell)
W34 (multipurpose fission warhead: Hotpoint).

The momentum built up during the Eisenhower years carried over into the Kennedy Administration, even though Defense Secretary Robert McNamara found SIOP-62 too rigid and apparently lacking in strategic rationale. The new administration initiated a rethinking of strategy and doctrine and introduced flexible options into the SIOP, but did not slow the entry of new weapons into stockpile. As a result, by the end of 1965 the following additional nuclear systems had become operational:

Strategic:

W38 (thermonuclear warhead: Atlas, Titan I)
B43 (thermonuclear bomb)
W53 (thermonuclear warhead: Titan II)
W56 (thermonuclear warhead: Minuteman II)
W58 (thermonuclear warhead: Polaris A3)
W59 (thermonuclear warhead: Minuteman I).

Tactical:

W44 (fission weapon: ASROC)
W45 (fission weapon: MADM, Little John, Terrier, Bullpup)
W48 (fission weapon: 155-mm artillery shell)
W50 (thermonuclear warhead: Pershing I)
W52 (thermonuclear warhead: Sergeant)
W54 (fission weapon: Falcon, Davy Crockett, SADM)
W55 (thermonuclear warhead: SUBROC)
B57 (multipurpose fission bomb).

Except for the gun-assembled W33, which required extensive field assembly before firing, all stockpiled weapons were now sealed-pit designs. While there was much innovative detail, and a few really new wrinkles yet to be worked out, the major inventions had been made and heavily exploited, and the basic patterns of nuclear-weapons technology had been firmly established.

THE STOCKPILE FROM 1965

Since 1965, the growth in the nuclear-weapons stockpile has shown a character entirely different from that of the first two decades. Referring once again to Figs. 1 and 2, we see that only 23 new systems entered stockpile in the 20 years 1966–1985 and that 15 systems were retired during this period. The functional makeup of the stockpile, that is, the proportions dedicated to strategic and nonstrategic missions, remains steady at the pattern established by 1965. This pattern is consistent with a view that little change in fundamental U. S. nuclear strategy has taken place over the last 20 years. Apparently, no nuclear innovation during this period has been sufficiently dramatic to once more induce sea changes like those of the 1940s and 1950s. To a large extent, turnovers in the stockpile appear designed to make more effective use of the technologies first developed in the 1950s in order to match weapon systems to military requirements.

This is not to say that the art and science of nuclear weaponry has not advanced during the modern era. Steady progress in basic weapon technology and a few major technical innovations have substantially enhanced the operational and logistical utility of nuclear weapons. To examine this in detail, we shall in the balance of this report adopt an organization centered on distinguishing weapons by the operational requirements they are designed to fill. Specifically, we shall develop the history of the stockpile in seven different categories:

- Strategic offensive: land-based ballistic missiles
- Strategic offensive: sea-based ballistic missiles
- Gravity bombs
- Air-to-surface missiles
- Tactical missiles
- Defensive weapons
- Miscellaneous tactical weapons.

Before a chronological survey of stockpile development is resumed, the more important advances of the past 20 years will first be described.

Basic Knowledge

While not an identifiable single technology, increased knowledge of basic weapon physics, materials properties and behavior, electronics, and computing technology have resulted in substantial steady improvements in nuclear-weapons design and construction. Weapons designers have been able to use their understanding of the physics of weapon function, plus the marked improvement in their ability to model weapon behavior, to eliminate unnecessary weight and fit a given yield into a smaller envelope. At the same time, miniaturization of weapon electronics and the development of new structural materials have made it possible to use more of the total warhead volume for the nuclear physics package. The result has been a steady improvement over the years in the yield-to-weight ratio, reductions in warhead diameter and size, and the ability to tailor weapons to particular delivery modes.

Safety

It is noteworthy that, over the span of more than 40 years, there has never been an accidental detonation of a nuclear weapon that produced a nuclear yield. However, there have been accidents with nuclear weapons, and there have been accidental detonations of high explosive (HE) in nuclear weapons. Requirements for one-point safety adopted and enforced many years ago have ensured that, even in the event of an accident sufficiently severe to detonate the HE of a nuclear weapon, no significant nuclear yield will result. However, explosion and fire can still result in the dispersal of weapons materials—most notably plutonium—that still present a significant hazard to indigenous populations and cleanup personnel. The most noteworthy such event occurred in 1966 near Palomares, Spain, when a B-52 carrying four

While controversy over MX basing has clouded the program almost from its beginning—and is not yet completely settled—the process of choosing a warhead for MX was also not serene.

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Segments of the Air Force strongly opposed this, however, arguing that Soviet construction of a new generation of "superhard" missile silos, control centers, and leadership bunkers made it imperative that the MX be used to improve U. S. hard-target kill capability. The March 1976 imposition of a 150-kt limit on nuclear test yields by the Limited Test Ban Treaty (LTBT) complicated the decision process. This meant that a new high-yield warhead for MX would have to be fielded without ever undergoing tests in its complete design configuration. Advocates of hard-target kill won the day fairly early on, but the specifics of the warhead remained uncertain for some time; for an extended period the W78 Mk-12A was carried as the baseline MX warhead. However, in early 1982 the Department of Defense (DoD) chose a new warhead, the W87, to be mated with the new Mk-21 reentry vehicle.

The W87 began the modern era of treaty-constrained development of high-yield warheads.

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Sea-Based Strategic Ballistic Missiles

October 1965 saw the last ballistic-missile nuclear submarine (SSBN) patrol of the Polaris A1 missile and the start of development of the Poseidon C3 missile for the new Poseidon boats. Only 5 years after the first Polaris SSBN had gone on station, the Navy was retiring the earliest elements of its first-generation SLBM force and was entering development of a second, MIRVed generation.

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Neither of the Polaris versions offered very good delivery accuracy, nor would this be a requirement on the yet-to-be-developed Poseidon C3. The primary mission of the SLBM force seemed to be to provide a secure retaliatory force, either to meet the requirements for finite deterrence, spelled out 10 years earlier by Arleigh Burke, or to pave the way for SAC bombers by knocking out defenses, as stipulated by President Eisenhower. In any case, the SLBM force was clearly designed for soft targets.

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The Trident program began as ULMS—Undersea Long-Range Missile System—in 1969 as a result of the STRAT-X studies. As a follow-on to Polaris/Poseidon, Trident was envisioned as a quieter submarine, carrying missiles that could be launched at intercontinental range. The need for Tri-

dent was driven by two primary considerations: a replacement for Poseidon would be needed before the end of its projected service life of 20 to 25 years, and the replacement submarines should operate over a wider range of ocean in order to ensure survivability against a growing Soviet surveillance and ASW capability. Development of the Trident I C4 missile and the Ohio-class Trident boat was approved by the Secretary of Defense in September 1971.

The Trident I missile was sized to allow retrofit into the smaller Poseidon SSBNs—a later Trident II missile will fit only the larger Trident boats. By the time the W76 warhead for the C4 was selected in 1973, the Navy had become more interested in missile range than in any further fractionation of payloads.

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liver its full load of eight W76 warheads to ranges greater than those attainable by an off-loaded Poseidon C3. Although the accuracy of the

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The W76 is the latest SLBM warhead to enter stockpile.

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complete the Navy's conversion from concentration solely on soft targets.

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Gravity Bombs

The story of gravity bombs since 1965 is to a large extent the story of the B61 bomb in all its variants. The B61, which entered Phase 3 development in January 1963, is a multipurpose modern tactical bomb, weighing approximately 700 lb, which now exists in eight models designed for air delivery by both strategic and tactical forces. Because the B61 is a truly multipurpose weapon, carried by a wide variety of U. S. and Allied aircraft dispersed all over the world, the development and refinement of B61 mods has been heavily influenced by requirements for safety and security. All B61 variants but one carry Permissive Action Link (PAL) arming systems, and some of the earlier mods that predated the introduction of IHE are now being replaced by versions employing an IHE primary and more elaborate safety and security systems.

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The Mod 0 employs a Category B PAL, requiring entry of a four-digit code to arm the weapon. The Mod 1 does not have the PAL (it is intended for Navy use); otherwise, it is identical to the Mod 0. Both of these early versions use PBX9404 HE.

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his version also incorporates command disable, which will destroy critical components of the warhead on coded command. The B61 Mod 5 is the last of the non-IHE versions.

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Beginning with the Mod 3, IHE has become standard equipment for B61s, along with weak link/strong link and unique sig-

in the strategic stockpile. Simultaneously, the intensified Soviet threat to Europe and the consolidation of U. S. nuclear strategy led to the introduction of large numbers of weapons designed for tactical/theater applications. During this period, the three legs of the strategic triad were established and the first SIOP was developed. While progress in nuclear-weapon technology continued to play a major role, technical advance across a broader front, including electronics and ballistic-missile technology, became very important. This era, perhaps more than any other, displays the symbiosis of nuclear and nonnuclear technologies in both prodding and responding to military requirements.

The fourth phase, extending from about 1965 to 1985, might be characterized as largely a period of refinement. While the total number of stockpiled weapons has varied over these years, the number of distinct types—mark numbers—has stayed relatively constant until the recent Reagan administration buildup. Second- or even third-generation warheads have replaced earlier systems, offering quantitative improvements in performance and operational characteristics. Technical advance in the state of the art in nuclear weaponry has continued, but military requirements have become the dominant force in determining the shape of the stockpile.

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LANL-A.

October 13, 1949

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TO: Technical Council Members

FROM: Edward Teller ~~CONFIDENTIAL~~

SUBJECT: THE SUPER BOMB AND THE LABORATORY PROGRAM

ADWD-2-7 ~~UNCLASSIFIED~~

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
1ST REVIEW DATE: 11/3/92 AUTHORITY: ☐ ADC ☐ DADC NAME: Stroud
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2ND REVIEW DATE: 11/16/93 AUTHORITY: ADC NAME: Kirsch

On Monday there will be a discussion in the Tech Council concerning the Laboratory program and in particular concerning the question whether our effort can be so increased as to make the Super Bomb feasible within the foreseeable future. I should like to present to you my views on this matter in this memorandum. In this way, I hope that more thought can be given to the question before Technical Council convenes.

I would like to outline why it is essential for us to develop a Super Bomb at the earliest possible time or else be able to say with reasonable confidence that the Super is not feasible. The arguments that have led me to this conclusion are of various kinds.

[redacted]

POLITICAL CONSIDERATION:

It is my conviction that a peaceful settlement with the Russians is possibl only if we possess overwhelming superiority. We do not now possess such superiority. The most promising prospect to acquire a great lead is by an early development of a Super Bomb. I am sure that such an accomplishment will in itself not solve the problem. Most difficult political questions will also have to be solved. But early possession of the Super Bomb will give us another chance in the political field. Without a Super Bomb such another chance is not likely to arise.

RUSSIAN PROGRESS:

The fact that an atomic explosion took place in Russia at this early a date has considerable significance. It seems that the Russian rate of progress is at least comparable to, if it does not exceed, the rate of progress in this country. The Russians have started working on the atomic bomb approximately in the summer of 1945. They are likely to have given consideration to the problem somewhat earlier but it is hardly probable that the total time of reasonably intensive effort in Russia has exceeded five years. This time is approximately the same as the time that was needed in this country to make and to explode an atomic bomb. Thus the rate of progress in R[redacted] is comparable to the rate at which we have been working during the [redacted] present rate of progress in comparison is far slower than in war[redacted]

It is probable that the Russians did not explore as many po[redacted]es bef[redacted] achieving an atomic explosion as we did. It is also prob[redacted] the Russians have not put into their atomic development th[redacted] horough and elaborate scientific and technical effort as we did. [redacted] therefore claim that their accomplishment is not equal to our wartime a[redacted]mplishment. If this is so, however, it merely proves that the elaborate precautions which we took in our atomic development was not absolutely essential. If the

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Russians continue to make actual progress faster and if we lose the atomic armament race, it will make little difference whether the reason has been the particular brilliance of Russian scientists or the exaggerated caution and thoroughness of our own group. [redacted]

A detailed possible picture of the Russian progress can be imagined along the following lines:

The Russians probably were familiar with the plans for the Canadian heavy water pile. The captured German scientists also knew of plans for heavy water piles. There are two major technical difficulties in the construction of such a pile. One is the fabrication of metallic uranium. This the Russians have probably learned from the Germans. The other is the production of great quantities of heavy water. There are several ways to accomplish this. One of the best techniques is the distillation of liquid hydrogen. The necessary low temperature technique is quite well developed in Russia. The Russians may therefore have had a pile of the approximate efficiency of the Chalk River pile as early as 1948 or even 1947. The extraction of plutonium from such a pile is a difficult job but can be more easily accomplished if the precautions taken for protection of personnel are less elaborate than those taken in this country. Such precautions are and must be a paramount consideration in our country but the same is not the case in Russia. A pile of the Chalk River type working steadily at 30 megawatts can produce material for a trinity bomb in less than a year. It can produce material for a gun gadget in two years. It is quite possible that the Russians have made a successful implosion. It is also possible, although perhaps somewhat less likely, that they have used the gun assembly and that the actual nuclear explosion was performed with a relatively inefficient gun gadget.

The above description gives the Russians credit for a minimum of scientific and technical progress. Even if this minimum is accepted, further Russian progress can be anticipated along the following lines. The Russians probably will build further heavy water piles. They may also build small piles working with some of the plutonium which the heavy water piles produce. These aims can be rapidly accomplished if no excessive demands are made with respect to high flux, resistance of materials for irradiation or with respect to breeding properties. The Russian rate of production of plutonium may equal the rate of our production within a year and indeed we have no absolute assurance that our production has not been already surpassed. It is therefore not impossible that the Russians should overtake us even in the matter of the stockpile which is the one item which never has been neglected in the United States.

An even more dangerous situation seems to exist with respect to neutron excess. This neutron excess is much greater for heavy water piles than it is for graphite piles and of course even greater for plutonium piles. [redacted] it is reasonable to assume that the Russians either are already ahe[redacted]n this respect or will be ahead of us in the near future.

The number of available excess neutrons is of decisiv[redacted] in several war time applications of atomic energy. [redacted] Among the[redacted]duction of tritium is probably the most important since tritium [redacted]uction is an important component in the production of the Super Bomb.

[redacted]

One of the first objectives would be to step up the date on which one can hope to produce a successful booster.

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TIME SCHEDULE:

If the Laboratory can marshall the necessary support from Washington for a really vigorous program, the problem of construction and detonating of a Super might be attacked with the same speed with which similar problems were attacked during the war. I realize that this program calls for an all out effort. However, I do not believe that anything less than such an all out effort would be commensurate with the responsibility which this Laboratory has undertaken with respect to the ultimate safety of the nation. It will be essential that all members of the Laboratory contribute fully any ideas they may have how to accomplish the technical details of this job.

[redacted]

[redacted]

[redacted]

[redacted]

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incorporated in dispersed weapons can be made solely in terms of broad policy considerations as to the desired objective."

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1.3.1.2 PAL General Characteristics (U)

(U) In September 1962, the Secretary of Defense approved a set of DoD design guidelines for PAL systems. These guidelines, entitled "General Characteristics for Permissive Devices for Use With Nuclear Weapons," or revisions thereof have served since that time as standards in specifying PAL devices in the MC of new weapons systems. The original guidelines and the four revisions (1969, 1970, 1972, and 1980) are included in Appendix B.

(U) The statement of purpose in the first edition of the General Characteristics of PAL defines:

> (U) "an arming control device for use with designated nuclear weapons which is intended to provide some additional physical means for preventing unauthorized use of nuclear weapons."[18]

(U) A number of specific design requirements are included. Most of these relate to specific operational features of the PAL system or to issues of compatibility with the rest of the weapons system. For instance, the PAL system

- (U) must not degrade weapon safety or reliability
- (U) must he compatible with weapon operational concepts as stated in the STS
- (U) must not significantly lengthen the reaction time for the weapon system

(U) These requirements are restated in all subsequent versions of the General Characteristics. However, as suggested in the Weisner memo, the objective of this system and its reason for existence is based on its ability to protect the weapon against unauthorized use by a potential adversary. Of the twelve specific design requirements stated in the original document, only one relates to the performance of PAL against an adversary.

[redacted]

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(U) Thus, the objective in terms of an adversary is not specified. However, some bounds are placed on the adversary's capabilities. The *function* of PAL is stated in terms of delay following unauthorized access to a weapon.

(U) In the 1969 edition, the stated purpose is

(U) "To provide general characteristics for permissive action links incorporated in weapons systems to prevent unauthorized nuclear detonation."[19]

[redacted]

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(U) In 1972, a new edition was prepared to include all existing PAL technology. While the statement of purpose remained essentially the same as in the 1969 edition, PALs are defined as

> (U) "devices and subsystems designed to reduce the possibility of obtaining a nuclear detonation from a nuclear warhead without the use (insertion) of a controlled numerical code, thus reducing the probability of an unauthorized nuclear detonation."[20]

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(U) Today, the commanders of the unified and specified commands to which nuclear weapons are allocated are responsible to the President and the Secretary of Defense to:

> (U) "establish and supervise the policies, practices and responsibilities for the storage, safety, security, custodial control, deployment, and utilization of nuclear weapons."[23]

(U) Explicit reference to PAL in relation to the theater commander's custodial mission and in particular to his weapon security responsibilities does not appear in either Ref 23 or 24.

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1.3.2.4 Related Documents (U)

(C) A letter from James P. Wade, Jr., Chairman of the Military Liaison Committee, to Duane Sewell, Assistant Secretary for Defense Programs, dated 18 April 1980, accompanied the current version of the PAL General Characteristics. This letter (Appendix C) comments on the role and function of PAL. The function of PAL as delay is emphasized. However, a broader role is presented for PAL than that envisioned in today's theater implementation.

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the JCS. This requirement states that all TNWs deployed to foreign soil will be PAL-equipped.

Responsibility for implementing and operating the PAL code-management system is delegated to the theater CINC. DOE b(3)

- (U) PAL must be compatible with all other weapon system requirements.
- (C) The function of PAL devices was historically recognized as delaying for a period of time, after unauthorized access to a weapon has been gained, the unauthorized detonation of that weapon. This is also the recognized function of PAL today.
- (C) The operational context in which today's theater PAL systems function suggests that PAL is one measure which protects against unauthorized use by US or Allied forces. Additionally, some benefit (delay) would be provided if outsiders (terrorists or host nation forces) were to gain access to a weapon. However, no explicit and agreed-upon definition of the threat against which PAL is intended to provide protection currently exists. Such definition would be useful in assessing the performance of todays PAL system.

2. PAL Systems Today (U)

(U) A third relevant document[28] from the office of the Assistant to the Secretary of Defense for Atomic Energy summarizes measures currently being implemented to upgrade the safety and security of nuclear weapons. Among the issues discussed in this document are

- Improvements in physical security to minimize the likelihood of loss of control of a nuclear weapon
- Stockpile improvement programs that address, among other things, modernization of the PAL protection in some of the older systems expected to remain in stockpile
- Modernization of DoD policy directives to clarify standards and criteria for positive control measures for nuclear weapon systems.

1.3.3 Summary of Objectives and Requirements (U)

(U) A review of historical and current documents and examination of today's theater PAL systems lead to the following conclusions:

- (S) The requirement for PAL originated at the Presidential level and is promulgated through

2.1.1 PAL Devices (U)

(U) Table 1 shows current and planned weapons by PAL device type. These devices are discussed below.

Table 1. Current PAL-Equipped Weapons (U)

Combination Locks	CAT A	CAT B	CAT D	CAT F
W31	W50	B28-RE	B28-0,-1	B61-3,-4
W33		B43-2	B61-2,-5	W84
W45-3		B57-2	(B61-6,-7,-8)	W85
W48		B61-0	W70-1,-2,-3	
W54			W79	
			(W80-0)	
			W80-1	
			(W81)	
			(W82)	
			B83	

Note: ( ) indicates weapon in development

2.1.1.1 Combination Locks (U)

(U) Most weapons—bombs delivered by aircraft, missiles, and shells—experience a unique environment during deployment, e.g., spin, acceleration, pressure change. To provide the desired preflight handling safety, a family of ESDs evolved which close critical electrical arming lines only after the weapon experiences the desired environmental signature. In the case of ADMs, manually set in place and fired by either command or timer, there was no launch, drop, or fire environment which could be sensed by an ESD. Installation of 3-digit combination locks provided an additional safety step in the prefiring sequence (Figure 2). The 3-digit locks were redesigned by the AEC to provide 5 digits to be compatible with a 4-digit split-knowledge code management system. The Army also developed combination locks for use on several weapon systems. About half of the European stockpile is still equipped with combination locks. They are used on the W31 Nike Hercules, W45 MADM, W54 SADM, M422 (W33/8-in. AFAP) and M454 (W48/155-mm AFAP).

(U) The M422 uses an Army lock. The M83 atomic weapon locking device screws into the projectile's base; one part (the locking tube and desiccant assembly) occupies the volume into which the breech-lock-fuze assembly must be installed before firing. The M454 uses an Army lock. The M76 atomic weapon locking device screws onto the projectile's nose, replacing the projectile's fuze (Figure 3). The W31 warhead for the Nike Hercules missile uses an Army lock. The M77 atomic weapon locking device fits onto the safing plug of the Adaption Kit (AK) (Figures 4 and 5). The W31 warhead for the Honest John missile uses an Army lock. The M81 atomic weapon locking device fits onto the safing plug of the AK (Figures 6 and 7).

(U) The W45-3 warhead for the MADM uses an AEC lock. The MC1885 padlock is installed on the warhead's J1 connector and prevents input of electrical signals to warhead circuits (Figure 8). The B54 warhead for the SADM also uses an AEC lock. The MC1948 lock-secured cover includes an MC1827 padlock (Figure 9). The cover denies unauthorized access to the arming and fuzing components.

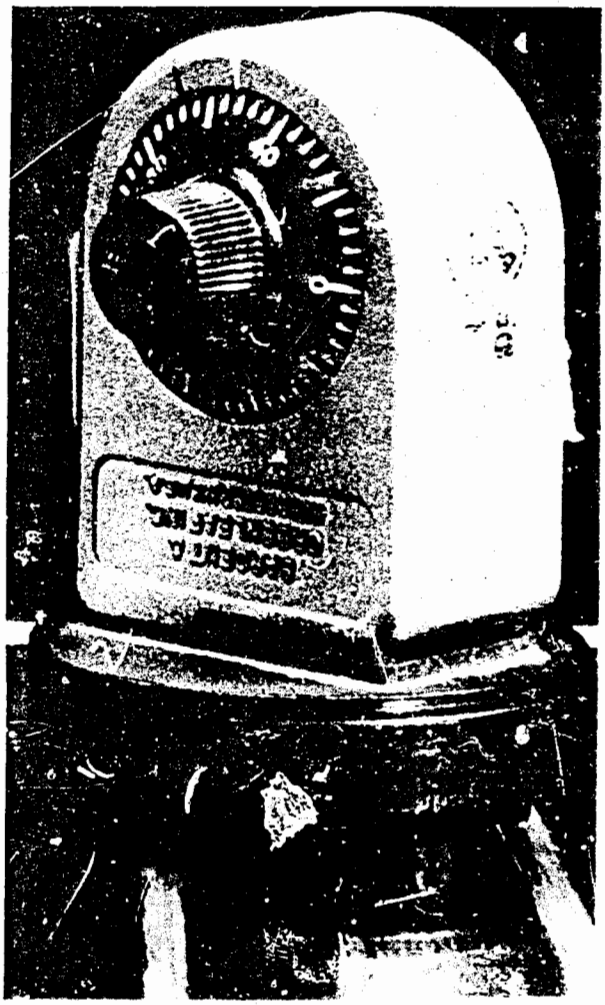


Figure 2. Combination Lock (U)

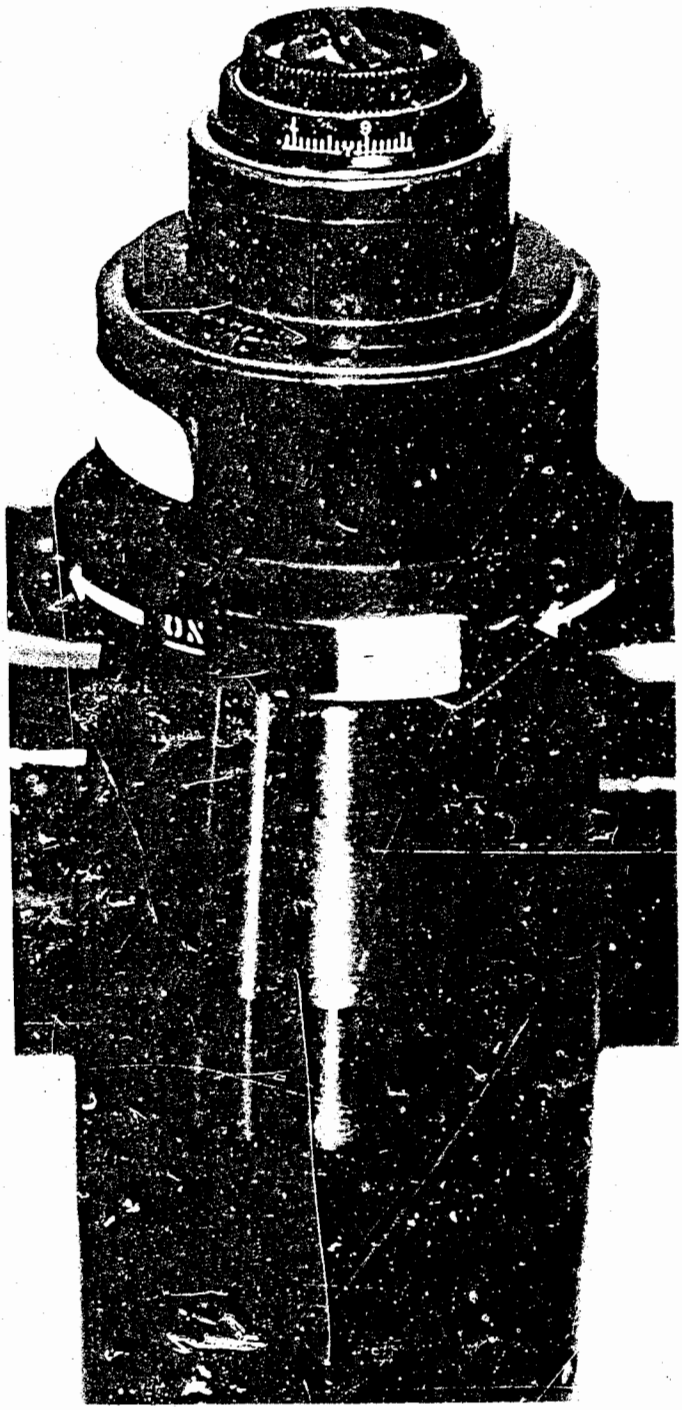


Figure 3. M70 Atomic Weapon Locking Device (L



Figure 4. M77 Atomic Weapon Locking Device (U)

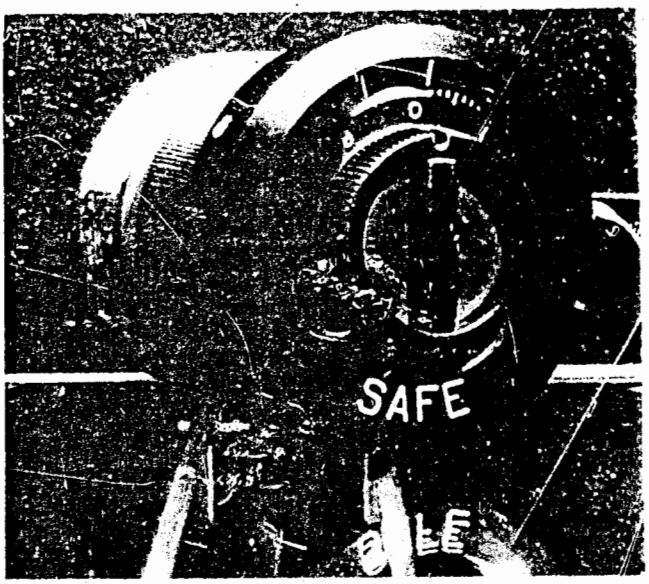
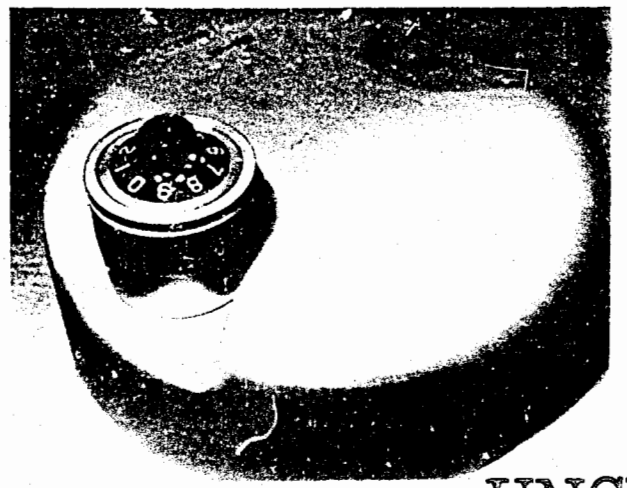


Figure 7. Mod Atomic Weapon Locking Device (U)



a



b

Figure 8. MC1552 Padlock (U)

(U) As originally fielded, the CAT B PAL system (Figure 11) included two electromechanical coded switches (MC1707s) in each weapon, two ground controllers (T1508 Decoder and T1509 Recoder), two controller testers (T1520 and T1521 for the Decoder and Recoder, respectively), three aircraft controllers (DCU117/A and DCU121/A, combined AMAC and PAL, and the DCU116/A PAL only), and a power source (T436 Battery). CAT B was installed only in bombs which have Air Force and Navy applications (primarily Air Force).

(U) The subsequent fielding of CAT D and F PAL has resulted in requirements for back-compatibility of CAT B with newer control equipment developed for CAT D and F. Today, CAT B PAL can be operated by the T1535 Ground Decoder; the T1536, T1555, and T1563 Recoders; the T1539 Verifier; and the DCU192, 196, 201, 218, 238, and 239, as well as those controllers listed earlier.

(U) The MC1707 (Figure 12) occupies a retangular volume of ~18 cu in., weighs ~ 2.2 lbs, and takes ~30 s to operate. It is used today in the B28-RE, B43-2, B57-2, and B61-0 bombs. Several improvements were made in the MC1707 design to overcome problems with the CAT A PAL system. The CAT B system requires 5 wires to recode, control, and monitor a weapon instead of the 14 required by CAT A. In addition, to minimize the impact on aircraft wiring, only three wires are required to control any number of switches operating in parallel, plus one wire per weapon to monitor the weapon's lock/unlock status.

(U) The CAT B system provides recode and code check capability for the stored codes without transferring the output contacts from the locked to the unlocked condition, or vice versa. Also, CAT B requires use of the stored code for a lock operation. This avoids possible accidental relock upon insertion of a wrong code after unlock. Finally, the recoders provide automated sequences of old code insertion, new code insertion, and code check operations.

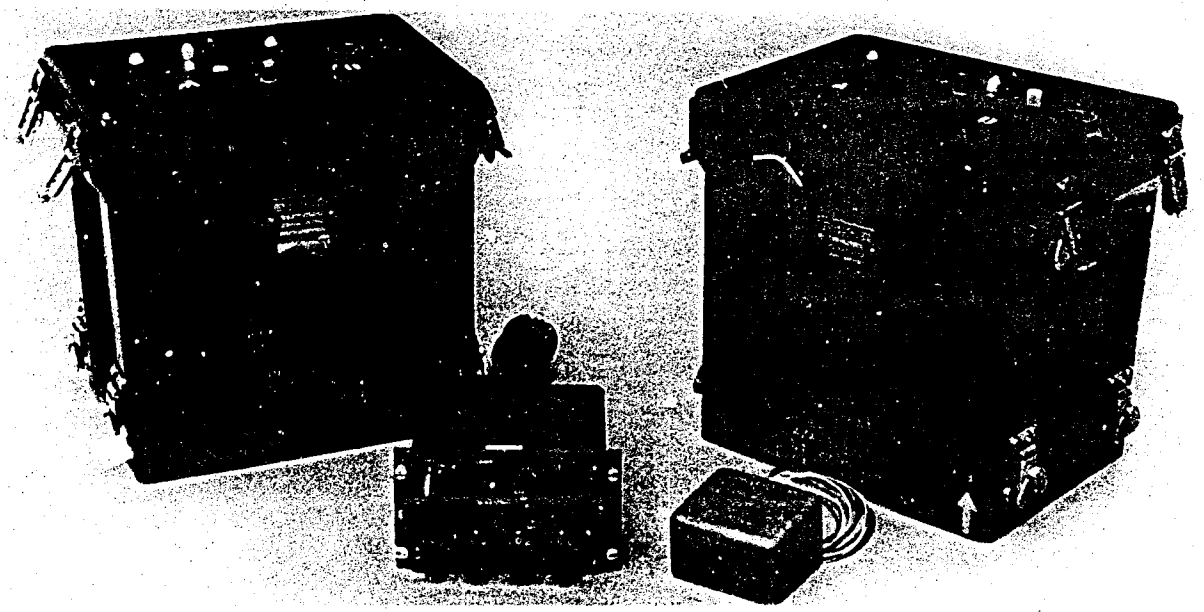


Figure 11. CAT B PAL System (U)



Figure 12. MC1707 (U)

2.1.1.4 Multiple-Code Coded Switch (U)

(C) A desire for selective unlocking through the use of multiple codes led to the concept of a multiple-code coded switch (MCCS). In May 1971, a requirement to incorporate an MCCS into the W74 was approved as Amendment 3 to the 155 mm Howitzer Projectile Military Characteristics. Miniaturization was essential because of the small volumes of the newer systems (W74 155-mm and W75 8-in. projectiles).

The MCCS design combined some new PAL-associated features with existing and still-required characteristics. They were:

- No power required for memory storage
- Compatible with aircraft cockpit control
- Knowledge of old code required for recode

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(C) The MCCS was developed as two separate items, the MC2764, ~17 cu in. (Figure 13), and the MC2907, ~1.5 cu in. (Figure 14). Both devices provide similar capabilities and are compatible with the same control equipment. MC2764 was developed on an accelerated basis to be available on an early timescale and is used in the W70-1 Lance and B61-2 CAT D applications. MC2907, with more difficult packaging concepts but employing basically the same hybrid microcircuit technology, was developed on longer timescales and is presently used or planned in the B28-0, and -1, B61-5, -6, -7, and -8, W79, W80, W81, and B83 CAT D applications.

DOE b(3)

2.1.1.5 Multiple Code Coded Security Switch (U)

(C) The MC3641 MCCSS, sometimes called GLCM Security Unit (GSU), is ~4.36 cu in. in volume and will be used with the GLCM to provide a 12-digit

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code capability (Figure 15). It will permit numerical assurance against bypass in accordance with DOD Directive 5200.16 in several scenarios associated with unauthorized launch.

DOE b(3) ID or serial number can be obtained upon query. Because the MCCSS is microprocessor-controlled and because of the different code length, a byte-oriented data format between the controllers and the MCCSS was chosen. The MCCSS will require new control equipment for recode and control. The T1563 Automated PAL Controller is being fielded on a timescale compatible with the GLCM for recode and APS maintenance control.

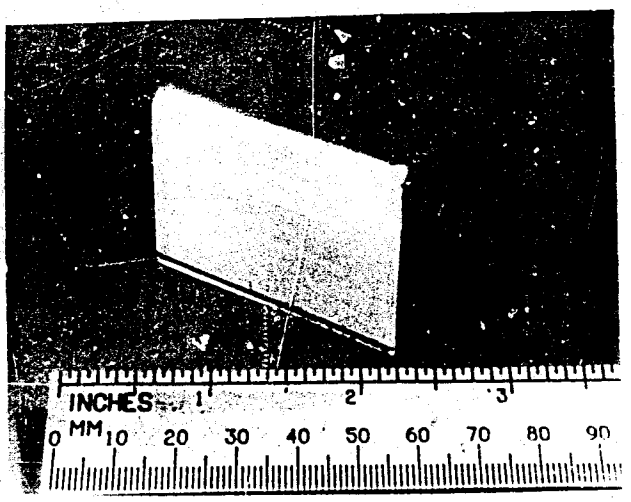


Figure 15. MC3641 (U)



Figure 13. MC2764 (U)

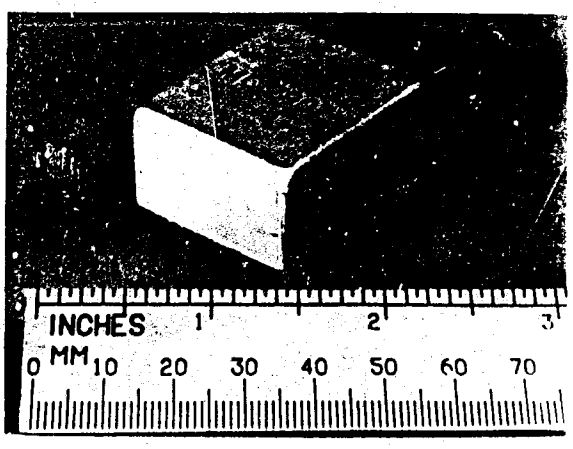


Figure 14. MC2907 (U)

2.1.1.6 Active Protection Systems (U)

DOE b(3)

2.1.2 Control Equipment (U)

(U) PAL control equipment has become very diverse and, in some cases, quite specialized. In most cases, control equipment was designed and developed by the DOE with DOE funds in response to DOD needs. Production has usually been managed by DOE and funded by DOD. There have been a few recent examples of specialized application (PII and GLCM) for which DOE specifications were provided, and design, development, and production were funded and managed by DOD. The categories of PAL control equipment are:

Recoders (Recode and Code Check)
Verifiers (Code Check)
Ground Decoders (Unlock and Lock Control)
Cockpit Decoders
Controller Testers

(U) The listing of Table 2 is believed to be complete. Newer controllers are back-compatible with earlier categories of PAL, except for CAT A. In most cases, older controllers have remained operational, particularly the decoders, because they are usually available and meet original operational requirements. Individual ground control items are discussed below.

Table 2. DOE-Supplied PAL Ground Controllers (U)

Item	Function	Quantity	FI U Date	PAL Category	Military Service
T1500A	Decoder	578	3/63	A	Army
T1501A	Recoder	57	3/63	A	Army
T1502	T1500/01 Tester	274	7/63	A	Army
T1508	Decoder	340	3/64	B,B′	AF/Navy
T1509	Recoder	39	3/64	B,B′	AF/Navy
T1520	T1508 Tester	442	4/64	B,B′	AF/Navy
T1521	T1509 Tester	39	4/64	B,B′	AF/Navy
T1526**	Recoder	17	8/73	C	Army
T1527**	Decoder	33	6/73	C	Army
T1533	Decoder	192	11/73	C,D,E,F	Army
T1534	Recoder	37	12/73	C,D,E,F	Army
T1535	Decoder	182	1/75	B,D,E,F	AF/Navy
T1536	Recoder	23	2/75	B.D,E,F	AF/Navy
T1539	Verifier	12	5/75	B,C,D,E,F	AF/Navy
T1547	CAT F Adapter	118		E,F	
T1549A	Controller Tester	147	6/75	B,D,E,F	AF/Navy
T1554	Decoder	308	1/81	D,E,F	Army/Navy
T1555	Recoder/ Verifier	40	4/79	B,D,E,F	All
T1563	Recoder/Controller	130*	10/83	B,D,E,F	All
T1565	T1563 HQ EQ	2*	7/84		All

* Estimates
** No Longer Used

2.1.2.1 T1500 Category A Decoder (U)

(U) The T1500 controller is used to unlock and lock the MC1541 coded switches (Figure 16). It drives the MC1541 motor to a position consistent with the code selected and set in the T1500, provides energy to open or close the output switches, and monitors the status of the MC1541. The T1500 weighs ~40 lbs with the T436 Power Supply attached. It controls two MC1541s simultaneously from the two independent channels and indicates when at least one of the MC1541 output switch sets closes.

2.1.2.2 T1501 Category A Recorder (U)

(U) The T1501 is similar to the T1500 decoder but has a code change capability (Figure 17). It selectively operates only one MC1541 coded switch at a time, first setting in the correct old code, then unlocking and preparing the switch for insertion of a new code. The new code is then set into the T1501 and the operation repeated, inserting the desired new code. An incorrect code must then be entered to relock the coded switch. This does not occur in an automated sequence but is done as separate operations for each of two coded switches in the weapon.

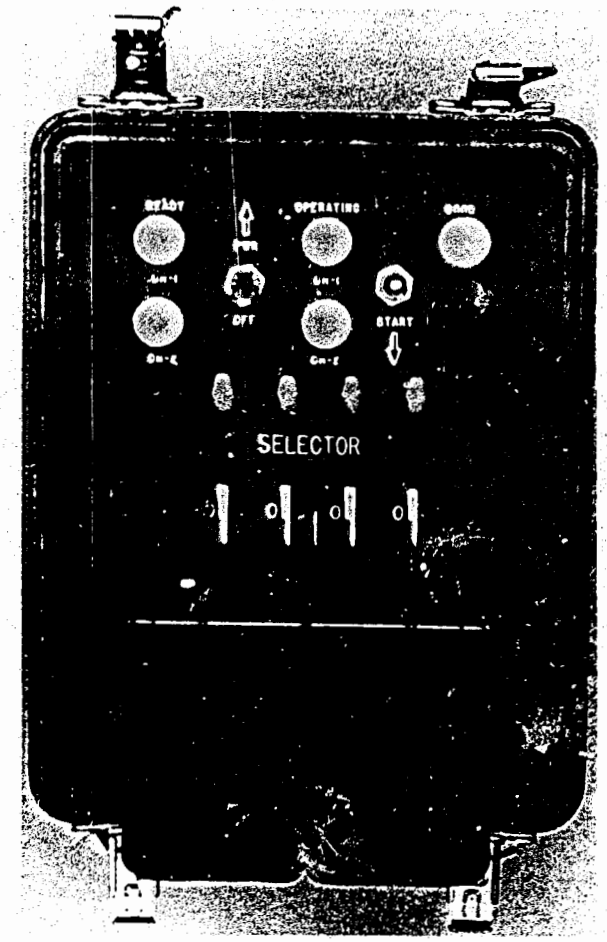


Figure 16. T1500 CAT A PAL Controller (U)



Figure 17. T1501 CAT A PAL Recoder (U)

2.1.2.10 T1536 Air Force/Navy Recoder for PAL Categories B, D, and F (U)

(U) The T1536 (Figure 26) is a controller used by the Air Force and Navy to recode and code-check the coded switch in a weapon; it can also be used to check the lock/unlock status of the weapon.

(U) A single-code or all-codes recode operation will always leave the weapon coded switch in the locked state. A code-check operation will not change the locked/unlocked status of the coded switch. The T1536 automatically recognizes a coded switch system as either single code (CAT B) or multiple code (CAT D/F) and furnishes the appropriate signals to the coded switch in a weapon. Power is supplied to the T1536 through a CT1478 cable from the T436B Power Supply. All of the necessary codes (one old and six new PAL codes) plus one new maintenance code are manually set into the T1536. After the codes are set, recoding or code-check is a single-cycle, semiautomatic operation.

2.1.2.11 T1539 Army/Air Force/Navy/ Code Verifier for PAL Categories B, C, D, and F (U)

(U) The T1539 is a controller used in the field by the Army, Air Force, and Navy to check code values in the coded switch in CAT B, B', C, D, and F PAL weapons; it may also be used to check the locked/unlocked status of the weapon. The T1539 recognizes a coded switch system as either single code (CAT B/B'/C) or multiple code (CAT D/F) and furnishes the appropriate address to the coded switch in the weapon. Power is supplied to the T1539 through a CT1478 cable from a T436B Power Supply.

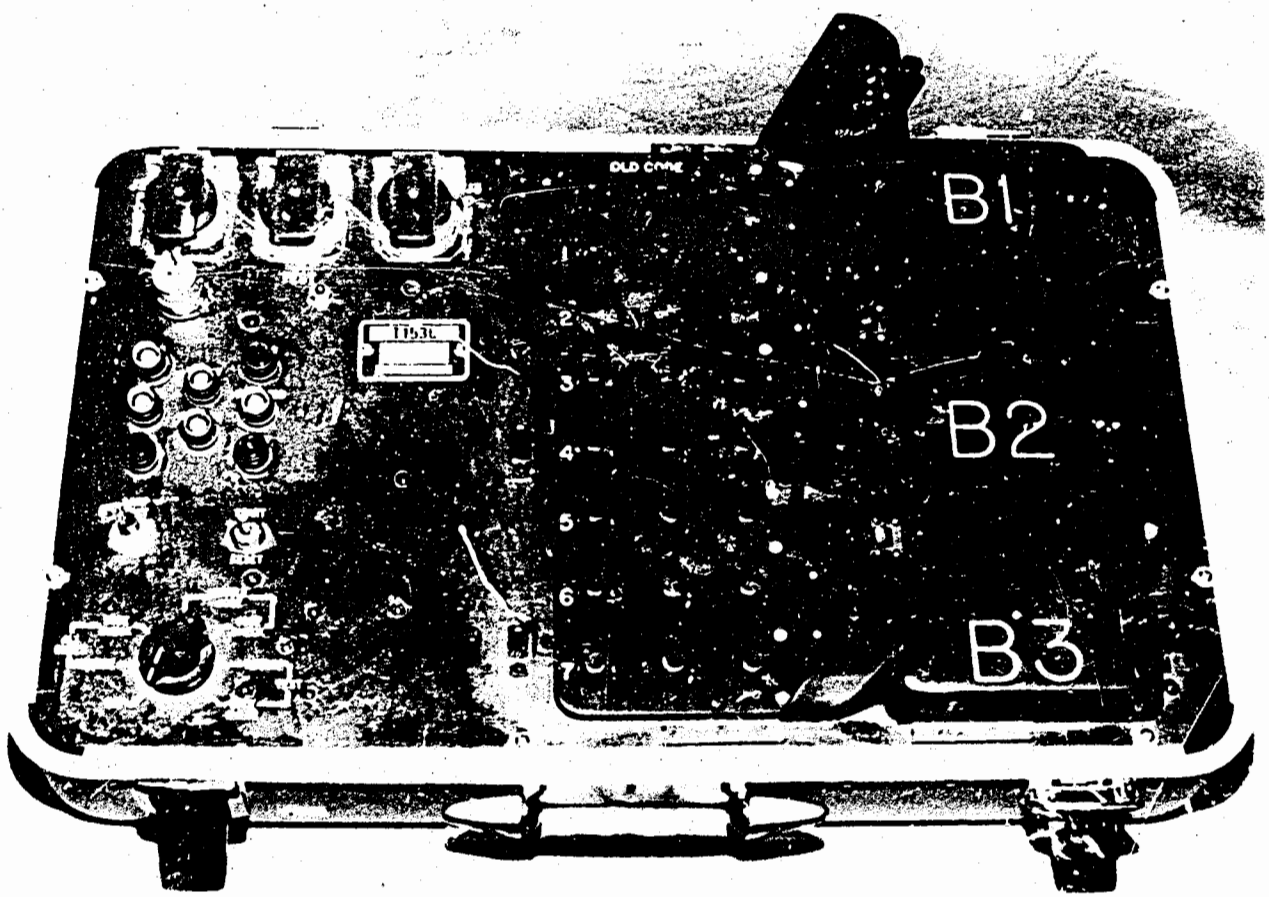


Figure 26. T1536 Air Force Recoder for CAT B, D, and F PALs (U)

2.1.2.12 T1547 Army/Air Force/Navy Adapter for Category F PAL (U)

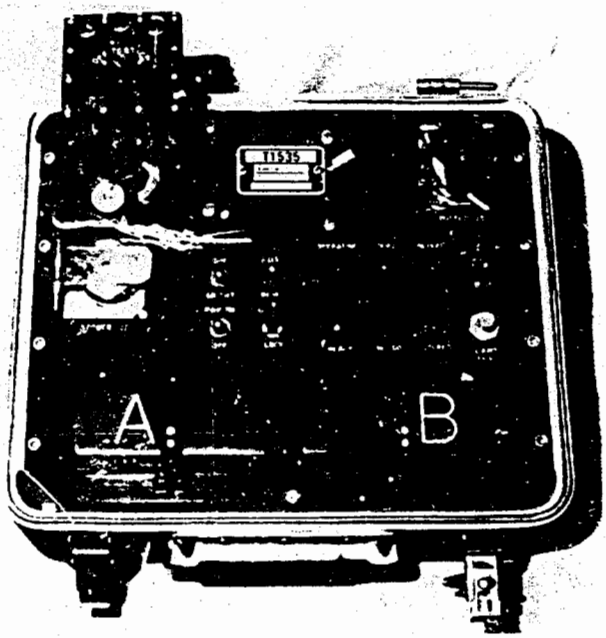


Figure 28. T1535 Decoder with T1547 Attached (U)

2.1.2.13 T1549A Air Force/Navy Programmer for PAL Categories B, D, and F (U)

(U) The T1549A performs two functions when connected to the new controllers. It performs a duration and amplitude check on the aircraft and ground controller output data and power circuits for CAT D and F PAL systems; it also functions as a coded switch simulator for CAT B, D, and F PAL systems for training in decoding operations with the T1549A, the aircraft, and T1535 Ground Decoder.

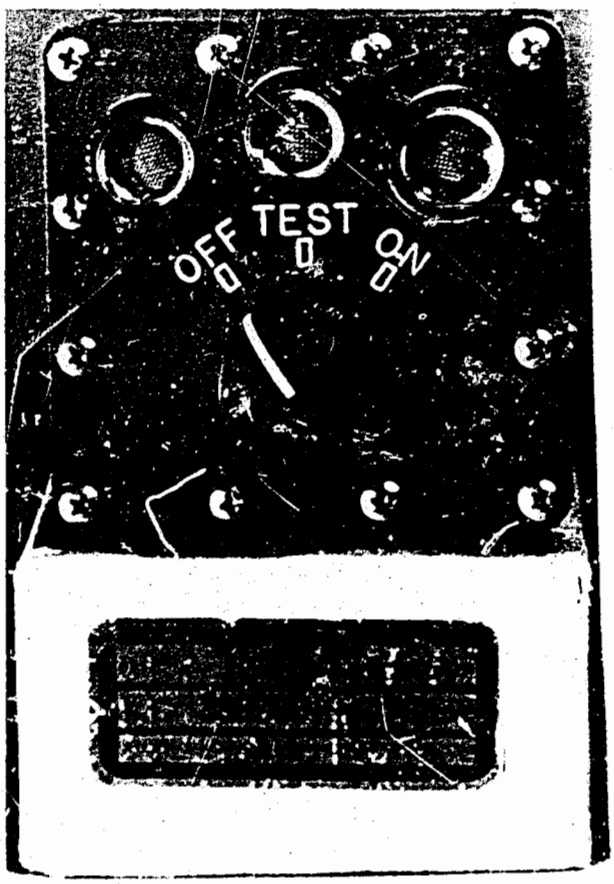


Figure 27. T1547 CAT F PAL Adapter (U)

(U) The T1549A furnishes feedback to the decoder which allows the operator to determine that an acceptable or unacceptable response has occurred. For training operations, storage of seven different codes is provided; any of these codes furnishes "off" and/or lock and unlock indications, as appropriate. The T1549A contains no control switches or monitor lamps. These responses are furnished by the controller to which the T1549A is interfaced.

Three cables are required for use with the T1549A. The CT1504 connects the T1535 Ground Decoder to the T1549A Programmer. This cable is currently used with all Air Force/Navy ground controllers. In addition, the CT1507 cable connects the T1549A to the pylon of the F4C, D, or E, and the CT1510 connects the T1549A to the F-111E aircraft pylon. No external or auxiliary power cable is required because the T1549A is powered by the ground decoder or aircraft safe power.

2.1.2.14 T1554 Army/Navy Decoder for PAL Categories D and F (U)

(U) The T1554 (Figure 29) is a controller used by the Army to lock or unlock the coded switch or to check the locked/unlocked status of the weapon. It is very similar to the T1533 except that it cannot be used to operate the single code CAT C System.

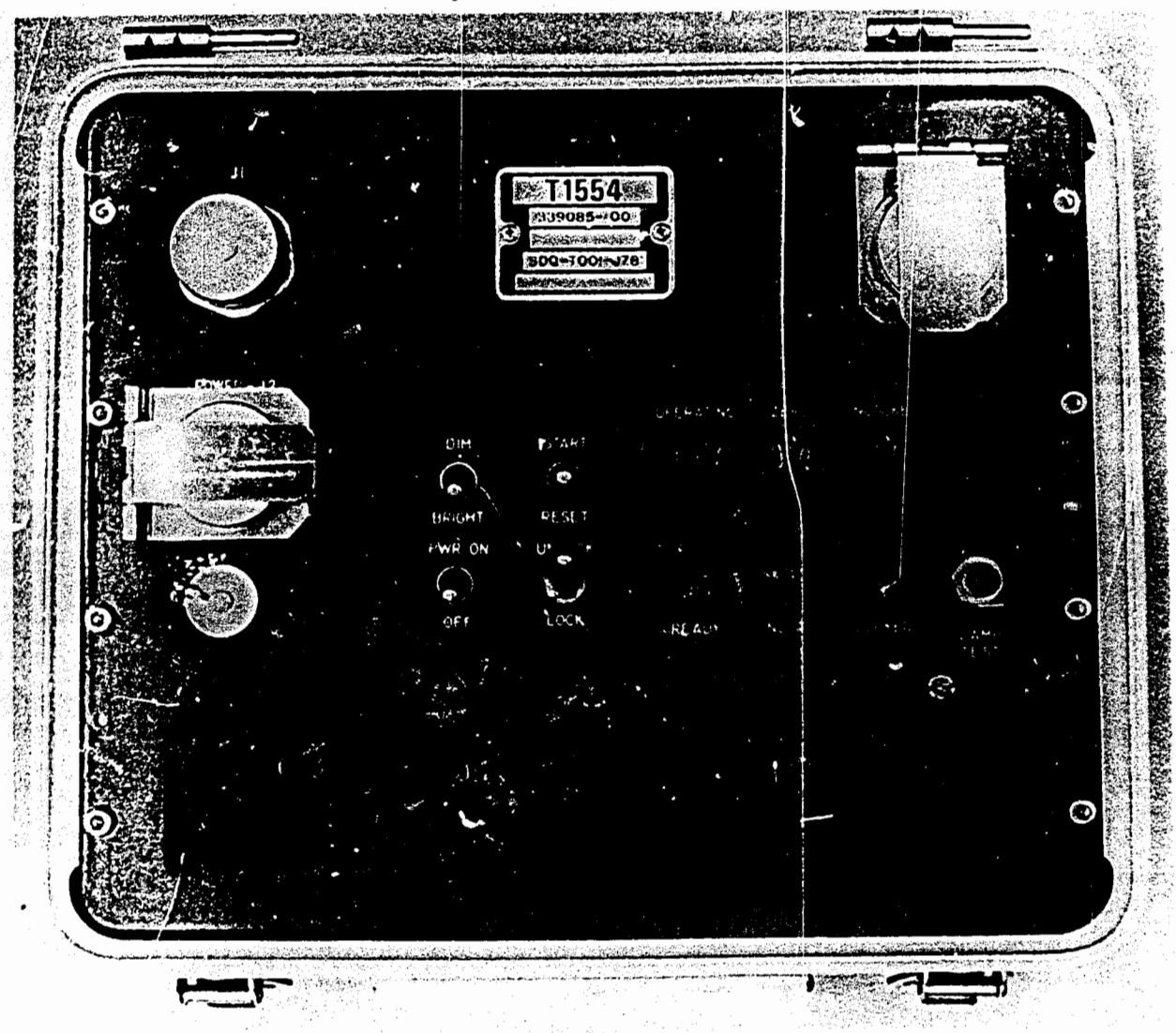


Figure 29. T1554 Army Decoder for CAT D and F PALs (U)

(U) The T1554 is not capable of a recoding operation. Power is supplied through the CT1478 cable from a T436B Power Supply or from a tactical vehicle's battery. If tactical vehicle power is used, the T1554 will operate with the vehicle either off or operating. The decoder was originally purchased to support the W79 system.

2.1.2.15 T1555 Army/Air Force/Navy Recoder/Verifier for PAL Categories B, C, D, and F (U)

(U) The T1555 (Figure 30) is a controller that can be used by all services as either a recoder or a code verifier. The T1555 by itself is a controller used in the field to verify the code values in the coded switch in CAT B, C, D, and F weapons and may also be used to check the locked/unlocked status of the weapon. With the T1558 plug adapter installed, the T1555 is a recoder used in the field to recode and code-check the coded switch in a weapon; it may also be used to check the lock/unlock status of the weapon. A single-code or all-codes recode operation will always leave the weapon coded switch in the locked state. A code-check operation will not change the locked/unlocked status of the coded switch. The T1555 automatically recognizes a coded switch system as either single code or multiple code and furnishes the appropriate signals to the coded switch in a weapon. Power is supplied to the T1555 through a CT1478 cable from the T436B Power Supply. All of the necessary codes (one old and six new PAL codes) plus one new maintenance code are manually set into the T1555. After the codes are set, recoding or code-check is a single-cycle, semiautomatic operation.

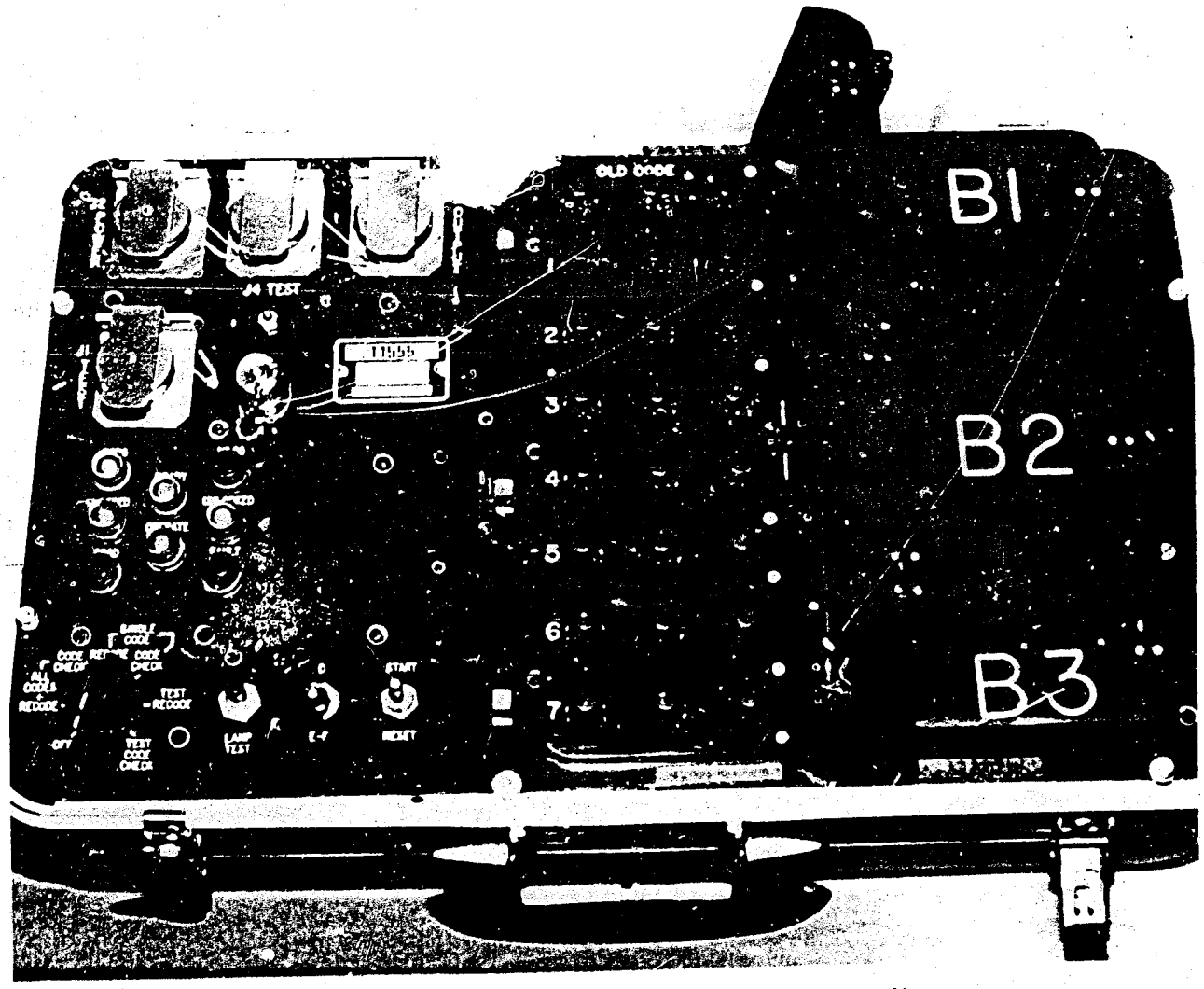


Figure 30. T1555 Recoder/Verifier for CAT B, C, D, and F PALs for Army/Navy/Airforce (U)

Table 3. Cockpit PAL Controllers (U)

Item	Function/Aircraft	Quantity	FPU Date	PAL Category	Military Service
DCU116/A (T1522)	PAL Only F4C,D,E/F111E	524	4/64	B	AF/NATO
DCU117/A (T1517)	PAL/AMAC F104/F100	1137	2/64	B	AF/NATO
DCU192/A	PAL Only F4C,D,E	314	6/68	B	AF/NATO
DCU121/A (T1524)	PAL/AMAC F100/F104	487	4/65	B	AF/NATO
DCU196/A37	PAL Only F4C,D,E	256	7/72	B,D,F	AF/NATO
DCU201/A	PAL/AMAC/USG F104	340	11/76	B,D,F	AF/NATO
DCU218/A	PAL/AMAC/USG F111F	111	1/78	B,D,F	AF/NATO
SWC-2	PAL/AMAC/USG MRCA Tornado	N/A	N/A	B,D,F	NATO
DCU-238	PAL/AMAC/USG/CD B52	292	7/83	B,D	USAF(SAC)
DCU-239	PAL/AMAC/USG/CD FB111A	77	4/83	B,D	USAF(SAC)

2.2.1.6.2 PAL Release Procedures in the European Theater (U)

(U) Weapon Deployment in the European Theater—In general terms, the mission of all US and Allied forces and weapons in Europe is to

> (U) "deter war by their presence and the credibility of their probable use and effectiveness in any conflict situation between Warsaw Pact and NATO forces"[30]

(U) To this end, US nuclear weapons have been deployed to locations in EUCOM for possible use by US and NATO forces. This deployment is made possible through bilateral programs of cooperation negotiated between the host NATO countries and the US.

[redacted]

DOE b(3)

(U) Weapon Employment in the European Theater—(U) In keeping with the NATO nuclear strategy of flexible response, planning for nuclear weapon employment in a European conflict encompasses options which range from massive response to very selective employment of a few weapons.

DOE b(3)

DOE b(3)

(U) As weapon and control hardware evolve, improvements and changes are expected to occur. Because a mix of old and new systems is likely to remain, it may not be possible to utilize some capabilities fully. Study of goals and requirements is warranted to give direction to acquisition of future systems.

4. PAL Advanced Development (U)

(U) Today's PAL hardware elements and code management system were described in Section 2. New concepts in both hardware and code management are now in various stages of development. These concepts are summarized in this section.

4.1 New PAL Weapon Systems (U)

(U) The W84 warhead for the GLCM, which is scheduled for deployment in late 1983, is the most recent PAL weapon system described in Section 2. Several other new systems are in various stages of development or production.

DOE
b(3)

(U) The W79 8-in. AFAP preceded the W84, entering Phase 6 production in September 1981. Ultimately the W79 will replace the W33 8-in. projectile in stockpile. However, a date for overseas deployment is uncertain at this time. The W79 is equipped with the MC2907 MCCS that provides CAT D PAL protection.

(C) The W85 PII warhead begins Phase 6 production in May 1983. Eventually, the improved PII system will replace many PIs presently deployed to NATO. The W85 is basically a B61-4, CAT F warhead adapted to the warhead section of the PII missile. As such, it is equipped with an MC2907A MCCS.

(C) The W82 155-mm AFAP that will replace the W48 projectile is presently scheduled to enter Phase 6 production in June 1986. No deployment date has been announced. The W82 will be equipped with the MC3764 CAP (Section 4.2). The CAP will provide the same multiple code population and limited-try features as the MCCS, but the W82 will not be maintained in a disenabled state by interrupting warhead circuitry. Instead, the CAP will be located outside the weapon in a Use Denial Lock (UDL). The UDL (Figure 44) is a device which fastens to the nose of the projectile, preventing installation of the fuze. Unlocking the CAP allows removal of the UDL. An Integrated Control Unit (ICU) in the shipping container of each round will provide unlock and relock control of the UDL (Figure 45).

(U) A factory-rebuild program is currently under way to upgrade early versions of the B61. The B61-6 will result from retrofitting the B61-0 with enhanced safety features and the MC2907 CAT D PAL. First Phase 6 production is scheduled for October 1985. The B61-8 represents a safety upgrade of the B61-2 and B61-5. The B61-8 will have an MC2907 CAT D PAL and is scheduled for initial Phase 6 production in January 1988.

(U) Four strategic systems with PAL are planned for the stockpile. Two of these are modifications of existing systems. The B28 (Mods 0 and 1) will be field retrofitted (beginning April 1983); B61-1 will be factory rebuilt (Phase 6 begins September 1985) into the B61-7. Present plans call for an MC2907 CAT D PAL in both systems. Two new strategic systems, the W80-1 warhead for the Air-Launched Cruise Missile (ALCM) (Phase 6 production began February 1982) and the B83 modern strategic bomb (Phase 6 production is scheduled to begin September 1983), also will be equipped with the MC2907 CAT D PAL.

(U) Two new PAL-equipped Navy systems are currently planned. Both the W80-0 warhead for the Tomahawk Sea-Launched Cruise Missile (SLCM) (Phase 6 production is to begin April 1984) and the W81 warhead for the SM-2 fleet air defense missile (Phase 6 production to begin November 1986) will have CAT D PAL (MC2907 or MC3764).

(U) A stockpile projection[31] (Figure 46) shows the planned distribution of PAL-equipped weapons (weapons with no PAL are not shown) through FY 1992. This projection reflects the planned production of weapons equipped with modern CAT D and F PAL devices.

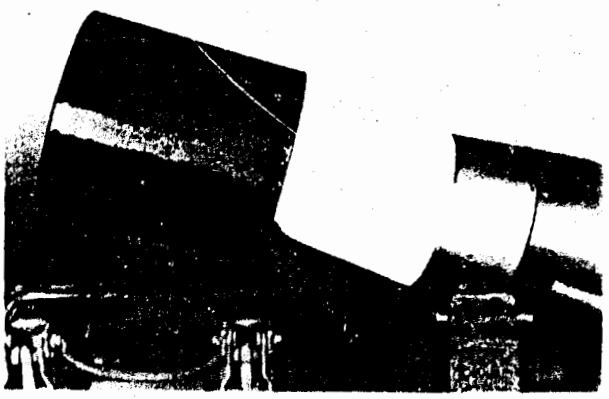


Figure 44. Use Denial Lock (U)

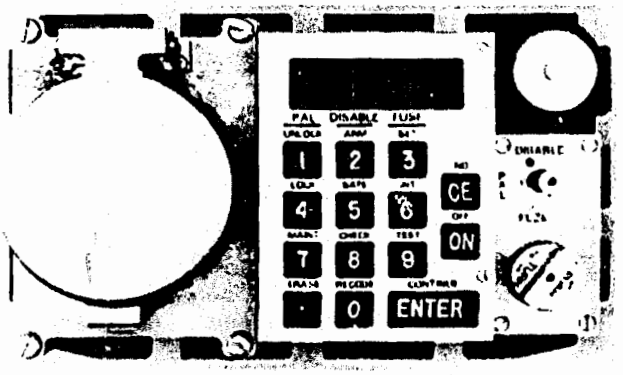


Figure 45. Integrated Control Unit (U)

(U) The HCP (Figure 47) is built around an HP 1000 computer. The system includes a printer, CRT display screen, keyboard, tape and disc storage units, and a cryptographic system. HCP operation is depicted in Figure 48. It has a number of functions. First, it provides access, under two-man control, to encrypted code information from the source data module generated by NSA. In addition, it contains a weapon data base that may be periodically updated.

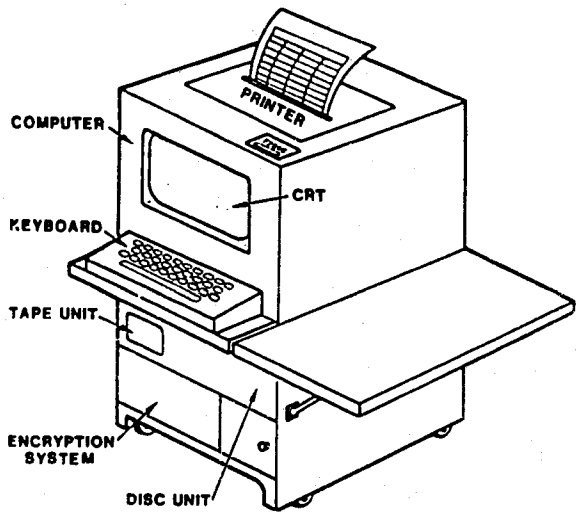


Figure 47. T1565 HQ Code Processor (U)

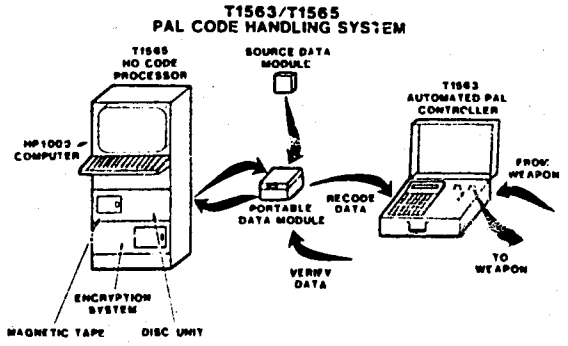


Figure 48. T1563/T1565 PAL Code Handling System (U)

This data base would include, for example, the theater weapon inventory information: mark and mod, serial number, and location of weapons in theater. Utility programs will be available for correlating the data base information with the weapon code information to aid in the construction of theater code plans. Given a theater code plan, the HCP will be able to generate the appropriate portable data modules for use by APCs during recode operations. The HCP will also be capable of reading monitor modules generated by the APC during recode. This may eliminate the need for on-site recode verification by the PMCT in cases where recode can be done with the APC.

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THE WHITE HOUSE
WASHINGTON

June 6, 1962

NATIONAL SECURITY ACTION MEMORANDUM NO. 160

TO: The Secretary of State
The Secretary of Defense
The Chairman, Atomic Energy Commission
The Director, Bureau of the Budget

SUBJECT: Permissive Links for Nuclear Weapons in NATO

1. After an examination of the problem of installing permissive links in nuclear weapons dispersed in NATO commands, I have decided we should now make the commitment to procure appropriate devices for all nuclear weapons, now dispersed and to be dispersed to NATO commands, for both non-U.S. and U.S. forces. (See attached memorandum to me from Dr. Wiesner dated May 29. This decision corresponds to Alternative 5 of that memorandum.)

2. This will require a supplementary appropriation for the Atomic Energy Commission budget. The Secretary of Defense, the Chairman, Atomic Energy Commission, and the Director, Bureau of the Budget will work out the details of the budget presentation.

3. At the earliest feasible time, the Secretary of Defense will submit for my approval a schedule for installation of these devices in NATO weapons. In making this schedule, the Secretary should consult with the Secretary of State on the political problems arising from the existence of weapons assigned to U.S. forces and weapons assigned to our Allies.

4. The Chairman, Atomic Energy Commission, in consultation with the Secretary of Defense, will carry out a research program on an urgent basis directed toward an examination of the feasibility and desirability of more advanced permissive link devices with a wider range of capabilities.

/s/ John F. Kennedy

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APPENDIX A

NSAM-160 and Wiesner Memorandum
Original Document Secret

MEMORANDUM FOR

THE PRESIDENT

At your request, I have reviewed, in consultation with the AEC and the DOD, the technical and cost aspects of equipping nuclear weapons dispersed overseas with permissive link hardware. The object of this review was to establish the program options that were technically available to implement such a program as rapidly as possible, and to determine the amount of supplemental funds that would have to be requested in the AEC FY '63 Budget to accomplish these options.

A decision on this problem involves the following basic policy issues which, while not technical in themselves, are affected by the availability of equipment and the program timing and cost:

(1) Should a permissive link be incorporated at this time in all dispersed nuclear weapons or just in those critical weapon systems with quick reaction, high yield and long range (e.g., Jupiter missiles and quick reaction aircraft)?

(2) Should a permissive link be incorporated at this time in all weapons dispersed to NATO (U.S. as well as non-U.S.) or just to non-U.S. weapons?

(3) Should a permissive link be incorporated at this time in weapons committed to NATO but based in the U.K. as well as weapons based on the European Continent?

These policy issues raised the more basic question as to what objective one is attempting to accomplish by incorporating a permissive link. A permissive link can attempt to meet any of the following objectives, each of which imposes increasingly difficult technical problems:

purpose of this review, I have not attempted to meet a specific objective but rather have analyzed the operational value of the best available equipment and attempted to determine how rapidly it could be incorporated in dispersed nuclear weapons.

While the permissive link equipment presently recommended by the AEC leaves something to be desired and can clearly be much improved with time, I believe that this equipment can be used as the basis for a crash program since development quality hardware exists and initial production and installation could begin in the immediate future.

Specifically the AEC recommends that, if a permissive link program is undertaken on a crash basis, bombs for aircraft and warheads for longer range missiles be equipped with an electro-mechanical lock which would have to receive a prearm numerical code in order to make the weapon operable. In the case of certain bombs which cannot be easily retrofitted with this equipment, as an interim measure pending the development of improved compatible permissive link hardware, mechanical combination locks would be installed to cover a socket into which an arming plug must be inserted. In the case of those bombs as well as short range missiles, such as Honest John and Mike Hercules, and the 8-inch shell, the arming plugs would be stored in self-destruct safes. The proposed program does not include specific hardware for the Davy Crockett missile which presents a particularly difficult problem because of its small size and possible forward deployment.

The numbers which would operate both the electro-mechanical and the combination lock could be held at any echelon or command. If circumstances required, the combination could be held by the U.S. custodial officer himself. This procedure could therefore give the weapons the same state of readiness that they now possess.

In evaluating the utility of this equipment, it must be recognized that it is simply intended to buy time. A specialist with proper equipment might be able to crack the electro-mechanical lock in a few hours time. If he were able to circumvent the self-destruct feature of a safe, a skilled locksmith could open a combination lock relatively quickly. In any event, it would also be possible for skilled technicians familiar with weapons to make these weapons operate in a period of from several hours to weeks, depending on the extent of thier knowledge, by opening the weapons and bypassing the electric circuits. Despite the limitations of this equipment, I believe it would give further (and probably decisive) protection against individual psychotics and would certainly cover unauthorized use by military forces holding the weapons during periods of high tension or military combat. While it would not assure that the weapons could not be used if they were forceably seized by an organized group or a foreign power with technically capable individuals, it would provide in the case of the more important weapon systems equipped with electro-mechanical lock a period of time, varying from hours to days, in which decisions could be made as to what our proper response to the seizure should be. The question of the legal and political requirements of control were beyond the scope of my review.

The question has been raised whether the installation of this development quality hardware on a crash basis might reduce the reliability of the nuclear weapons. However, in view of the simple nature of this equipment and the method of installation, I believe that it is now generally agreed that it would not reduce the inherent reliability of the weapons. The weapons would, of course, not be operable if the combination number were not received from a higher headquarters. This is a communication and management problem, which can be very simple or a very complex, depending on the level of command at which the combination number is held and the degree of control maintained through coding procedures or the use of different combination numbers for different weapons. In its simplest form, it should be possible to handle this procedure wherever a "go code" can be transmitted which is presently a requirement if any control is to exist. In any event, I wish to emphasize that, if circumstances demand, a decision can be made to release the combination number to the U.S. custodian with the field unit and thereby revert to the state of readiness and control that exists today.

At my request, the AEC has estimated the cost and time for completion of the following five alternative programs, which I believe represent the full range of possible application of the permissive link on a crash basis to nuclear weapons dispersed to the European Theater:

The estimated completion date, total cost, and FY '63 for each of these programs is as follows:

Alternative	Estimated Date Completed Installation	Total Cost ($ Millions)	FY '63 Cost ($ Millions)
I	June 1963	3.2	3.2
II	Oct. 1963	11.3	10.6
III	Dec. 1963	13.6	11.7
IV	Mar. 1964	18.6	13.8
V	Aug. 1964	26.9	14.0

A supplemental to the AEC FY '63 Budget would call for obligation of the total cost of the program but expenditure of only the FY '63 cost of the program.

On the basis of this review, I have concluded that it is technically possible to equip on a crash basis all nuclear-weapons dispersed to the European Theater with reasonably effective permissive link equipment at relatively small cost. Therefore, the decision as to the extent to which permissive link equipment should in fact be incorporated in dispersed weapons can be made solely in terms of broad policy considerations as to the desired objective.

Whatever decision is made on the crash program to install permissive link equipment on dispersed nuclear weapons equipment, I would recommend that a vigorous program be undertaken to develop an improved electronic lock which would be incorporated directly in the electronic package associated with all future weapons so that the option of a permissive link would always exist. This program should also include work to develop improved devices to retrofit the bombs and medium range missiles which were equipped with combination locks only as an interim measure in the above crash program. I would also recommend that there be an agressive research program to develop more advanced concepts of the permissive link including mechanics to assure the self-destruction of a weapon if efforts were made to by-pass the permissive link. It is my understanding that the AEC has funds available to cover the R&D necessary for these advanced programs.

Jerome B. Wiesner

APPENDIX B

General Characteristics for PAL Devices
Original Document Secret

Item I

GENERAL CHARACTERISTICS FOR PREMISSIVE DEVICES
FOR USE WITH NUCLEAR WEAPONS (U)

General Characteristics
Approved by the OSD:
13 September 1962

1. Purpose. These General Characteristics define an arming control device for use with designated nuclear weapons which is intended to provide some additional physical means for preventing unauthorized use of nuclear weapons.

2. General Characteristics. The device shall conform to the general characteristics and provide the capabilities listed below:

a. The device shall be capable of repeated enabling, disenabling, and recoding. Further, the device shall be capable of being maintained in either the enabled or disenabled mode.

b. When the device is enabled, a positive indication of enabled condition shall be provided. It is highly desirable that this indication provide no usable information to an unauthorized operator.

c. The time required for authorized enabling of the device shall not add to the weapon system reaction time under any readiness condition. Capability for inflight operation of this device is required for certain aircraft applications.

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e. The device and associated equipment shall be designed so that inspection or disassembly of the weapon will not disclose the combination or code.

f. The combination or code shall be transmitable by all standard communications means, and shall be capable of being changed rapidly and accurately by persons having the appropriate equipment and the old combination or code.

g. The device shall be so located and shall function in such a manner that it will permit performance of the required weapon maintenance, retrofit, and test operation throughout the stockpile-to-target sequence, without enabling the device.

h. The device and associated equipment shall be of such quality as not to decrease significantly the weapon reliability.

i. The device and its associated equipment shall be designed so as to permit installation and use of the device in bombs or warheads without degrading weapon safety.

j. The device installed in the weapon itself should not degrade the delivery capability or alter the ballistics of the weapon system.

k. Meters, dials, and switches on device components which are used in the open without blackout protection shall be illuminated in such a manner that blackout will not be violated.

l. The device and its related equipment shall withstand, without functional impairment or reduction of operational reliability, the environmental criteria specified in the applicable stockpile-to-target sequence of authorized weapon applications and in assoicated environmental specifications.

5. Inspection & Maintenance.

a. The system shall be designed so that inspection or disassembly of any component external to the warhead will not disclose the codes.

b. The permissive action link shall be so located and the system shall function in such a manner that it will permit perormance of the required warhead maintenance, retrofit (including internal and external components exclusive of the permissive action link system), and test operations throughout the STS without changing the mode of the device.

c. The system shall be capable of having maintenance performed on it in either the enabled (unlocked) or disenabled (locked) mode.

d. The operational storage life of that portion of the system installed in the warhead shall be no less than that of other warhead components.

6. Control Equipment.

a. Control equipment with the exception of decoders installed in aircraft shall be designed to permit disenabling (locking) and enabling (unlocking) using the "two-man" concept, and recoding using the "two-team" concept.

b. Control equipment shall provide a positive indication of the mode of the permissive action link device. This indication should provide no information regarding the set code.

c. Decoders shall be capable of enabling (unlocking), disenabling (locking), and code checking.

d. Recoders shall be capable of recoding and code checking the system without enabling (unlocking) the device.

e. Design alternatives which combine decoders and recoders are acceptable.

7. Environmental Considerations.

a. Meters, dials, and switches on componenets which are used in the open without blackout protection shall be illuminated in such a manner that blackout will not be violated.

b. The system and its related equipment shall withstand, without functional impairment or reduction of operational reliability, the evironmental criteria specified in the applicable stockpile-to-target sequence of authorized weapon applications and in associated environmental specifications.

Item 3

GENERAL CHARACTERISTICS FOR
PERMISSIVE ACTION LINK SYSTEMS USED WITH NUCLEAR WEAPONS (U)
(Attachment to DDR&E Letter to Chmn, AEC, same subject, 31 Dec 1970.)
(Original Document Secret)

1. Purpose. To provide general characteristics for permissive action links incorporated in weapon systems to prevent an unauthorized nuclear detonation. This document is not intended to inhibit in any way development of improvements beyond the characteristics set forth.

2. General.

[redacted] DoE b(3)

b. The system shall provide for two modes, unlock and lock of the warhead by insertion of one 6-digit decimal code.

[redacted] DoE b(3)

d. The system shall not significantly degrade weapon reliability, nor shall it degrade safety, or delivery capability. The time required for unlocking the device shall not unduly add to the weapon system reaction time under any readiness condition.

3. System Operation.

a. The control equipment must provide visual indications of the status of the system. As a minimum, the equipment must indicate when (a) the number of unsuccessful unlocking attempts is zero, (b) the number of unsuccessful unlocking attempts is greater than zero but less than that required for lockout, and (c) the device is locked out.

b. The system shall be capable of recoding, unlocking or locking at any point in the STS:

(1) in the case of aircraft weapon systems, up to the time of taxi and/or aircraft launch; and enabling (unlocking) or disenabling (locking) after aircraft launch.

(2) in the case of projectiles, at any time up to the time of loading into the weapon breech.

(3) in the case of missile systems, up to the time of final prefire operations.

c. The code shall be capable of being changed rapidly and accurately by persons using the appropriate equipment. Changing of the code will be dependent upon possession of the old (existing) code.

d. At anytime prior to permanent lockout the feature which counts the number of incorrect tries shall reset to zero whenever the proper code is inserted.

e. The system shall be capable of a code check operation which will allow verification of the set code without changing the mode of the device.

4. System Compatibility and Reliability.

a. The system shall be compatible with the weapon operational concepts to include the readiness requirements stated in the STS.

b. The system will be compatible with normal logistical movement in either selected mode.

c. The system shall be electrically compatible with other weapons system circuitry. In the case of aircraft systems it will be compatible with aircraft circuitry during all phases of circuit operation, both ground and air.

d. The design of control equipment shall preclude permanent locking if a permissive action link operation is interrupted by power failure.

e. The system shall incorporate a means of determining electrically, by a T-304 or similar service continuity test equipment, whether the permissive action link device in the unlocked condition.

[redacted] UNCLASSIFIED

Item 4

GENERAL CHARACTERISTICS FOR
PERMISSIVE ACTION LINK SYSTEMS USED WITH NUCLEAR WEAPONS
(Attachment to DDR&F Letter to Chun, AEC, Same Subject, 26 July 1972)
(Original Document Secret)

1. Purpose To provide general characteristics for AEC-produced electromechanical/electronic permissive action link (PAL) systems used with nuclear weapons to prevent an unauthorized nuclear detonation. This document is not intended to inhibit in any way development of improvements beyond the characteristics set forth.

2. Nomemclature

[redacted]

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3. Definitions

Permissive Action Link (PAL) – A family of devices and subsystems designed to reduce the possibility of obtaining a nuclear detonation from a nuclear warhead without the use (insertion) of a controlled numerical code, thus reducing the probability of an unauthorized nuclear detonation.

Passive Protection – Precludes operation of weapon arming circuits.

Active Protection – Senses attempts to gain unauthorized access to weapon arming circuits, with option to respond by initiating weapon disablement.

Mode – Refers to the protected condition (LOCK) or the unprotected condition (UNLOCK) of the PAL.

State – Refers to the condition of the active protection feature (OFF/TEST/ON).

Unlock Code – A preset code used to unlock the PAL.

Off Code – A preset code used to change state of OFF.

Code Check – Confirms stored code(s) in PAL without affecting weapon PAL mode.

Recode – Allows changing of stored code(s) in PAL.

Code Inhibit – Precludes a second unlock of a PAL with a given code until recode.

Limited-Try – Counts consecutive incorrect code trials and resets to zero on a correct code trial.

Temporary NO-GO – Precludes additional code trial operations without special field equipment after a number of incorrect code trials.

Permanent NO-GO – Precludes additional code trial operations with field equipment after additional incorrect code trials.

4. General Characteristics

A. Category A and Category B [redacted]

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2. These systems shall provide for two modes, UNLOCK and LOCK of the PAL by insertion of one 4-digit decimal code.

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B. Category B'

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3. The system shall provide for two modes, UNLOCK and LOCK of the PAL by the insertion of one 4-digit decimal code.

C. Category C – The characteristics stated above (Category B') apply with the following modifications:

1. The system shall provide for two modes, UNLOCK and LOCK of the PAL by insertion of one 6-digit decimal code.

D. Category D

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C. (U) All Categories

(U) 1. The system shall be compatible with the weapon operational concepts to include the readiness requirements stated in the STS.

(U) 2. The system shall be compatible with normal logistical movement in any selected mode.

(U) 3. The system shall not significantly degrade weapon reliability, safety or delivery capability. The time required for unlocking the device shall not unduly add to the weapon system reaction time under any readiness condition.

(U) 4. The system shall be capable of being recoded, code checked, unlocked or locked at any point in the STS up to:

a. (U) In the case of missile systems, up to the time of final pre-fire operations.

b. (U) In the case of aircraft weapon systems, up to the time of taxi and/or aircraft launch, with unlocking or locking after aircraft launch. However, recode is not required after weapon loading on aircraft.

(U) 5. The system shall contain a Master Recode feature to allow recoding of all stored codes using any one of the old codes which has not been inhibited.

(U) 6. The system shall be capable of being recoded rapidly and accurately by persons using the appropriate equipment.

4. (U) CONTROL EQUIPMENT

A. (U) All Categories

(U) 1. The system shall be electrically and mechanically compatible with the weapon system. In the case of aircraft systems, any equipment installed in the aircraft or associated with the weapon will be compatible with aircraft circuitry during all phases of aircraft operation, both ground and air.

(U) 2. The system shall incorporate a means of determining electrically, by service continuity test equipment, whether the PAL is in the unlocked condition.

(U) 3. The control equipment must indicate when (a) the number of unsuccessful trial attempts is zero; (b) the number unsuccessful code trial attempts is greater than zero but less than that required for NO-GO; and (c) the device is NO-GO.

(U) 4. Control equipment shall be provided that will:

a. (U) Allow recoding and code checking without unlocking the PAL.

b. (U) Allow recoding any one or all unlock and off codes using one not inhibited stored code.

c. (U) Allow code checking all stored codes in one operation or code checking any one of the stored codes.

d. (U) Allow unlocking and locking the PAL.

e. (U) Allow PAL unlocking and locking operations in an aircraft to be performed by a single individual.

(U) 5. New control equipment shall minimize potential TEMPEST, tampering, and bugging vulnerabilities. DoE b(3)

5. (U) INSPECTION AND MAINTENANCE

A. (U) All Categories

(U) 1. The system shall be designed so that inspection or disassembly of any component external to the warhead will not disclose the codes.

(U) 2. The PAL system shall function in such a manner that with the active protection OFF, warhead maintenance and test operations can be performed without changing the mode of the passive protection.

6. (U) ENVIRONMENTAL CONSIDERATIONS

A. (U) All Categories

(U) 1. The system and its related equipment shall withstand, without functional impairment or reduction of operational reliability, the environmental criteria specified in the applicable weapon stockpile-to-target sequence.

(U) 2. Meters, dials, and switches on components which are used in the open without blackout protection shall be illuminated in such a manner that blackout will not be violated.

APPENDIX C

Letter from J. P. Wade, Jr., to D. C. Sewell



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DEPARTMENT OF DEFENSE
MILITARY LIAISON COMMITTEE
TO THE
DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20301

April 18, 1980

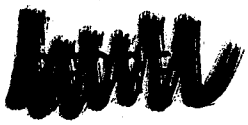
Honorable Duane C. Sewell
Assistant Secretary for
Defense Programs
Department of Energy
Washington, D.C. 20585

Dear Mr. Sewell:

(U) Over the past several months a great deal of concern and discussion has surfaced involving the policy for non-violent disablement and what role it should play in nuclear weapon security matters. Specific controversy has centered on questions of: which weapons should have a disable capability?; what level of sophistication should be credited to the threat?; and how long should disablement render the weapon useless against this threat? Department of Defense guidance to the Department of Energy in this area has been presented in systems Military Characteristics and POG meetings, as well as in the Nuclear Weapon Development Guidance. Unfortunately, in many cases it has been less than specific or subject to interpretation in application.

(U) I would like to clarify the existing situation and toward that goal, two transmittals are enclosed. The first is a DoD statement of policy addressing the goals and current assessment needs associated with nuclear weapon disablement systems. The second is a revision of the July 1972 "General Characteristics for Permissive Action Link Systems Used with Nuclear Weapons."

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(U) The paper "General Characteristics for Permissive Action Link Systems Used with Nuclear Weapons" should be viewed as the basic DoD definitions for PAL systems in acquisition of weapon systems incorporating DoE produced PALs. This paper, that supersedes the original 1972 document and amendments, will be forwarded to DNA for handling in a manner similar to weapon military characteristics, that is DNA will be responsible for publication and maintenance of an up-to-date file including amendments that may occur in the future. Consistent with our intention to work toward standardization of PAL devices and associated control equipment, only three PAL systems, Category D, E, and F are addressed in this update of the paper. Earlier PAL devices continue to remain in the stockpile: however, their acquisition cycle has been completed and therefore they have not been included in this update of the characteristics document.

Sincerely,

/s/ James P. Wade, Jr.
Chairman

Attachments
a/s (SFRD)

APPENDIX D

DoD Directive S-5200.16
September 22, 1970

APPENDIX E

JCS Pub 13, Volume II
(Excerpt From Chapter 7)

APPENDIX F

Excerpt From Amendment 3 to the Military Characteristics for a Nuclear Warhead for the 155 mm Howitzer Projectile (Approved by the MLC 27 April, 1971)

3. Control Devices

3.1 Security Container System (SCS)

An SCS, compatible with projectile and warhead designs, will be used with the M517 on an optional basis. The SCS will be developed under a program separate from the XM517 development program. The SCS shall be designed and function as specified in the SCS Characteristics attached as an Appendix.[2]

3.2. Permissive Action Link (PAL)

The PAL shall conform to the general characteristics outlined in the letter from the Director of Defense Research and Engineering to the Chairman of the Atomic Energy Commission, "General Characteristics for Permissive Action Link Systems Used with Nuclear Weapons," dated 31 December 1970.

3.2.1. The PAL control equipment shall also operate and be capable of recoding the SCS six-digit, limited-try coded switch.

3.2.2. It is desired that the control equipment be compatible with Category B, six-digit single code PAL devices.

3.2.3. The system shall provide for two modes, unlock and lock for the warhead by insertion of one six-digit decimal code. Unlock shall occur upon the insertion of any one correct code of six preset unlock codes. These unlock codes may be preset so that each is unique, or so that redundancies occur among them.

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VERIFIED UNCLASSIFIED
Per LMR 6-11-79
By Marcia Ballegos 3-7-96

PUBLICLY RELEASABLE
Per Jay Brown, FSS-16 Date: 8-4-92
By Marcia Ballegos CIC-14 Date: 3-7-96

L A Report 18

August 9, 1943

This document contains 30 pages

THE COLLAPSE OF HOLLOW STEEL CYLINDERS BY HIGH EXPLOSIVES

WD - Principles + Testing

WORK DONE BY:

H. Bradner

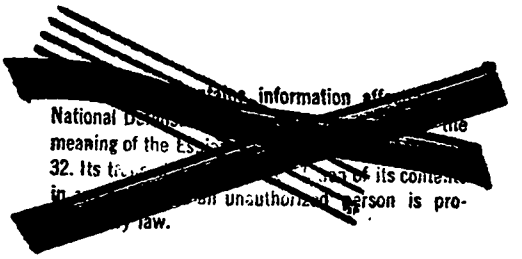
S. Neddermeyer

J. F. Streib

REPORT WRITTEN BY:

S. Neddermeyer

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ABSTRACT

Part I gives a very simple approximate one-dimensional treatment of the terminal velocity imparted to a rigid mass by a mass of high explosive. The one-dimensional treatment is presumed to be approximately valid for the cylindrical case provided the charge thickness is small compared to the radius. The result may be expressed to a good approximation by means of the simplified formula $v = \frac{m_e}{m}\sqrt{\frac{2\,u_o}{1+m_e/m}}$, where m_e/m is the ratio (mass of explosive/mass of projectile) and u_o is the initial internal energy per unit mass of the exploded gas, assumed to be initially at uniform pressure and temperature. In Part II the mechanics of the cylinder itself is treated from simple energy arguments using the assumption of a constant yielding stress, and the result of Part I is applied to estimate the attainable collapse ratio as a function of the mass ratio of explosive and cylinder. In Part III a few new experimental data are considered. The observed collapse ratios are found to be in rough agreement with the ones calculated for RDX if one assumes an effective yielding stress of 300,000 lb/in^2. The observed mass ratios for TNT are however found to be high by as much as 50%. The discrepancy can be attributed to several things: (a) The theoretical mass ratios are only approximate and are probably too low. (b) The assumed value for the yielding stress for steel (10-20 carbon, cold drawn) may be too high and may have a lower effective value when the collapse is rapid than when it is slow. The origin of the discrepancy can be settled by measurements of the rate of collapse, or by direct measurements of heat generation. These experiments are now in progress.

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THE COLLAPSE OF HOLLOW STEEL CYLINDERS BY HIGH EXPLOSIVES

I. MAXIMUM VELOCITY GIVEN TO A PROJECTILE

A correct treatment of the motion imparted to a projectile by a charge of high explosive involves a number of factors which complicate the dynamical problem of taking into account simultaneously the motions of the whole system of projectile plus exploded gas: (a) The equation of state is rather complicated because of the extreme initial pressure and density. (b) The equilibrium of combustion products presumably shifts as the hot gas expands, and (c) The detonation wave leaves the exploded gas with a residual momentum and a non-uniform pressure distribution. A very rough preliminary treatment which is of some use in correlating experimental data may be given on the following basis. (a) The motion is assumed to be one-dimensional. This should be a fair approximation for "implosions" of cylindrical or spherical shells in which the charge thickness is small compared to the radius. (b) The detonated explosive is assumed to be initially an ideal gas at uniform pressure and density. (c) The projectile is assumed to remain at rest while receiving the impulse from the explosive. Assumption (b) is presumably a fair approximation if the explosive is detonated in several directions at once, and (c) can be valid only for small ratios, m_o/m, of explosive mass to projectile mass.

On this basis we assume that only the boundary layers of the detonated explosive move, forming a discontinuous shock wave in the outside air and a discontinuous rarefaction wave moving into the exploded gas which is assumed to maintain the initial pressure p_o until the rarefaction wave

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passes. The last assumption is not a valid one as the rarefaction wave cannot remain discontinuous, but is used only as a crude approximation to represent some kind of an average motion of the wave front. A rigorous solution for the case of an ideal gas is given by Streib in another report.

Referring to Fig. 1b, we then assume that there are three regions of constant pressure p_o, p' and the outside atmospheric pressure p_1, that rarefaction and shock waves travel with constant velocities v, v'_1, and that the boundary between expanded gas and compressed air travels with constant velocity v'. The conservation laws for mass, momentum and energy may be written down in the form:-

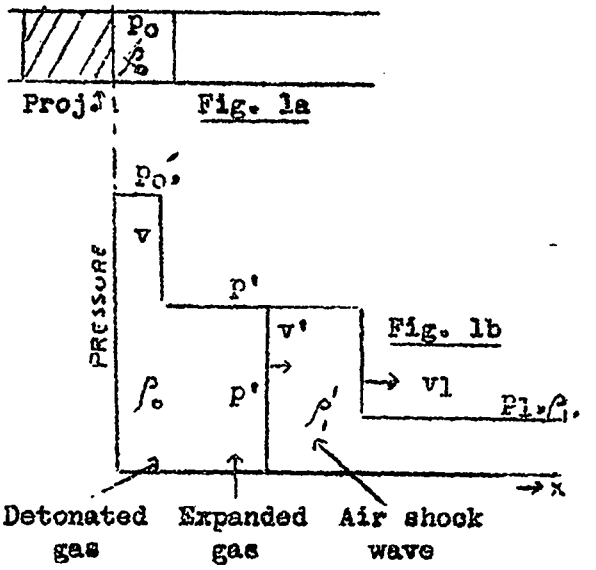


Fig. 1a

Fig. 1b

(1) $$\rho_o v = \rho'(v + v')$$

(2) $$p_o - p' = \rho_o v v'$$

(3) $$\frac{1}{\gamma - 1} p_o v = \left(\frac{1}{\gamma - 1}\frac{p'}{\rho'} + \frac{v'^2}{2}\right)\rho_o v + p'v'$$

} Rarefaction front

(4) $$\rho_1 v'_1 = \rho'_1(v_1 - v')$$

(5) $$p' - p_1 = \rho_1 v' v'_1$$

(6) $$\left[\frac{1}{\gamma - 1}\left(\frac{p'}{\rho'_1} - \frac{p_1}{\rho_1}\right) + \frac{v'^2}{2}\right]\rho_1 v'_1 = p'v' - p_1 v'_1$$

} Shock front

Here $\frac{1}{\gamma - 1}\frac{p}{\rho} = u$ is the internal energy per unit mass.

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These are readily solved for the two equations in v':-

$$v'^2 = \frac{x + \gamma - 2}{\frac{\gamma}{\gamma - 1}\frac{x}{x - 1} - \frac{1}{2}} u_1 = \frac{(1 - \mu x)}{\frac{\gamma}{\gamma - 1}\frac{\mu x}{1 - \mu x} + \frac{1}{2}} u_o$$

where $u_1 = \frac{1}{\gamma - 1}\frac{p_1}{\rho_1}$ $\qquad u_o = \frac{1}{\gamma - 1}\frac{p_o}{\rho_o}$

and $x = \frac{p'}{p_1}$; $\mu = \frac{p_1}{p_o}$; $\mu x = \frac{p'}{p_o}$.

Now $x >> 1$ and $\mu x << 1$ so that to a good approximation

$$v' = \sqrt{2u_o} \qquad \text{and} \qquad x = \frac{\gamma + 1}{\gamma - 1} \cdot \frac{u_o}{u_1}$$

and the velocity of the rarefaction wave is

$$v = \frac{p_o - p'}{\rho_o v'} \simeq \frac{p_o}{\rho_o v'} = (\gamma - 1)\sqrt{\frac{u_o}{2}}$$

Thus from the equation for v'^2 we see that the kinetic energy of the expanding gas comes out to be approximately equal to the initial internal energy of the detonated explosive. Tables 1 and 2 give some applicable data for several different explosives. As the ideal-gas relation for the internal energy $u_o = \frac{1}{\gamma - 1}\frac{p_o}{\rho_o}$ is not applicable to the highly compressed explosive gas we make direct use of the calorimetric measurements of the energy of explosion and put this equal to u_o.

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TABLE 1. MEASURED HEATS OF EXPLOSION (for loading density 1.5)
(Kistiakowsky, OSRD # 293)

EXPLOSIVE	HEAT OF EXPLOSION	DETONATION VELOCITY (meas.)
TNT	650 cal./g/	6700 meters/sec
Tetryl	890	7200
PETN	1410	7600
Cyclonite (RDX)	1240	7800

TABLE 2. PROPERTIES OF PRODUCTS OF ADIABATIC CONSTANT-VOLUME EXPANSION
(Calculated) (Brinkley and Wilson, OSRD # 1231)

EXPLOSIVE	LOADING DENSITY	TEMPERATURE	PRESSURE
RDX, Comp B	1.61	3140° K	98.8×10^9 dynes/cm^2
TNT	1.46	2910°	65.4
50/50 Amatol	1.58	2480°	79.8

For RDX, density 1.5, one then gets

$$x = \frac{p'}{p_1} = 163$$

$$\frac{1}{\mu x} = \frac{p_o}{p'} = 610$$

$$v' = 3.2 \times 10^5 \text{ cm/sec.}$$

$$v = 0.65 \times 10^5 \text{ cm/sec.}$$

The total momentum given to the projectile per unit sectional area will then be, for small charges of length l_o

$$P = p_o l_o / v = \rho_o l_o v' = m_o v'.$$

Alternatively,

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(7) $$v_p = \frac{m_o}{m} v' = \frac{m_o}{m}\sqrt{2u_o}$$

is the maximum velocity imparted to the projectile of mass m per unit sectional area.

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This suggests that a somewhat better result may be obtained by a direct overall application of the conservation laws, if one assumes the internal energy to be divided between projectile and ejected gases. The equations are

$$m_o u_o = \frac{m_o}{2} v'^2 + \frac{m}{2} v^2$$

$$m_o v' = mv.$$

The solution is

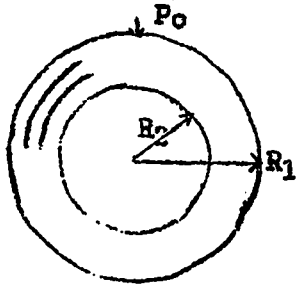
$$(8) \qquad v = \frac{m_o}{m} v' = \frac{m_o/m}{\sqrt{1 + m_o/m}} \sqrt{2u_o}$$

This is plotted in Fig. 2 for RDX and TNT using the measured values of u_o from Table 1. In the figures and in all that follows the notation m_e, ρ_e, r_e, h_e has been used for the mass, density and dimensions of the explosive charge.

II. MOTION OF THE CYLINDER

The pressure existing in a detonated high explosive is of the order of 10^6 lb/in^2, which is much higher than the yielding strengths of any ordinary metals. In treating the motion of a collapsing shell we therefore assume that there is plastic flow against a constant yielding stress throughout the shell.

For the simple preliminary treatment we ignore volume changes and therefore any effects of elastic waves. The shell is assumed to receive an initial inward impulse from the pressure p_o and thereafter to move freely against the yielding stress. This assumption is not quite valid because the velocity of the rarefaction wave into the exploded gas is $\sim .6 \times 10^5$ cm/sec., which is of the same order as the velocity attained by the shell; this should not however seriously invalidate the results. The motion may then be treated by the energy equation $K = K_o - W$ where K is the



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kinetic energy of the shell at any stage of the motion, K_o is the initial kinetic energy, and W is the work done at that stage against the internal stress. If W and K_o are known then the velocities of the inner and outer surfaces can be calculated as a function of the collapse ratios. K_o is calculated from Equation (8). In applying Equations (7) and (8) as approximations to a cylindrical or spherical case it may be noted that in (7) the mass ratio should be taken as $\rho_e t_e/\rho t$ where t_e and t are the thicknesses of explosive and shell, whereas in (8) one should presumably take the actual mass ratio. However, since (8) approaches (7) for small mass ratios and must in any case represent an upper limit, we have used $m_e/m = \rho_e t_e/\rho t$ in all that follows. In the worst case this is about 0.6 the actual mass ratio.

Work of collapse

The pressure required to deform a thin cylindrical shell of radius r and thickness Δr, against a constant yielding stress s, is

$$p = \frac{s\Delta r}{r} .$$

If the volume change is neglected then the volume of the thin shell is $\Delta V = 2\pi r \Delta r = \text{const.}$, and the work required to collapse the shell to a radius r' is

$$\Delta W = -\int_{r}^{r'} 2\pi r p dr = s\Delta V \int_{r}^{r'} dr/r = s\Delta V \ell n(r/r') .$$

Let R_1, r_1 be the initial and final outside radius and R_2, r_2 the initial and final inside radius. The total work to collapse a thick shell from R_1, R_2 to r_1, r_2 is

$$W = s \int \ell n \frac{r}{r'} dV .$$

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If we use the constant-volume relation

$$r^2 - R_2^2 = r'^2 - r_2^2; \quad R_1^2 - R_2^2 = r_1^2 - r_2^2$$

$$W = \frac{\pi s}{2} \int_{r_2}^{r_1} \ell n \frac{R_2^2 - r_2^2 + r'^2}{r'^2} \, d(r'^2)$$

with the notation

$$\lambda = \frac{R_2}{R_1}; \quad x = \frac{r_1}{R_1}; \quad y = \frac{r_2}{R_1}, \quad \text{(called the "inner collapse ratio")}$$

the total work per unit mass w, may be written

$$(9) \qquad w = \frac{W}{M} = \frac{s/2\rho}{1 - \lambda^2} \left\{ y^2 \ell n y^2 - x^2 \ell n x^2 - \lambda^2 \ell n \lambda^2 \right\}.$$

Here x, y and λ are related by the constant-volume condition

$$x^2 - y^2 = 1 - \lambda^2.$$

In Fig. 3, $w/(s/2\rho)$ is plotted as a function of y for two values of λ. We put $w = v^2/2$ where v is the equivalent initial velocity to produce the collapse ratio y and in Figs. 4 and 5 we plot v against y for three values of the yielding stress and for two values of λ. For these curves $\rho = 7.5$, whereas it should be about 7.8 for the steel cylinders of Part III. The curves of Figs. 6, 7 were derived from Figs. 4, 5 by using Fig. 2 to convert equivalent initial velocity to mass ratio.

Rate of collapse

The kinetic energy may be shown to be

$$K = \frac{M v_2^2}{2} \frac{y^2}{1 - \lambda^2} \ell n \frac{x^2}{y^2} + \frac{M v_2^2}{2} f(y)$$

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where v_2 is the velocity of the inside surface, and x, y and λ are connected by the same constant volume condition as before: $x^2 - y^2 = 1 - \lambda^2$. If we write $w = (s/2\rho)g(y)$ then the energy equation is

$$(v_2^2/2)\, f(y) = v_o^2/2 + (s/2\rho)\, g(y).$$

This may be used to find v_2 as a function of y for any assumed value of v_o^2. For the case of "critical collapse" $f(0) = 0$, so $v_o^2 = -(s/\rho)\, g(0)$. The kinetic energy function f(y) is plotted in Fig. 8 for various values of λ, and in Fig. 9 the inner velocity for the critical case has been plotted as a function of collapse ratio with $\lambda = .667$, $s = 300{,}000$ lb/in^2. The inner velocity is also shown for the same initial velocity, but no resisting stresses. In this case $v_2 = v_o/\sqrt{f(y)}$.

III. EXPERIMENTAL RESULTS

For the preliminary experiments, which were of necessity done with meagre equipment, the aim has been first to observe the main features of the phenomena when metal shells undergo extreme and rapid plastic flow under external pressure, and to make an empirical determination of the relation between collapse ratio and mass ratio. These experiments are being followed by observations of the velocities and times of collapse, for which several direct methods have been devised.

About 30 experiments have been carried out with mild steel cylinders ranging in diameter from 3" to 6 5/8" and in wall thickness from $\frac{1}{4}$" to $1\frac{1}{2}$". The explosive used first was TNT crystals packed to a density of about 0.87 g/cm^3, and in all the later experiments, a plastic explosive called "Composition C", which is a mixture of finely powdered RDX (88%), also called "Cyclonite", and vegetable oil (12%). An assembly typical of that usually used is shown in Fig. 10, which is drawn to scale for Experiment # 26.

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The results of 16 experiments are listed in Table 3 in which the figure numbers correspond to the photographs. The experiment numbers are marked on the samples in the photographs. All the analyzable data are included in Table 3, as well as a number of typical examples of the sort of fragmentation occurring when large charges are used.

Analysis of the data; stability of collapse

The greatest difficulty in obtaining interpretable experimental results arises from the instability which necessarily exists when the wall thickness is small compared to the radius. This is further enhanced by the non-uniform pressure left by the detonation wave. The detonation wave effect can be reduced by using multiple detonations, started simultaneously by tying several primacords of the same length to one blasting cap; four detonation points, spaced evenly around the circumference at the middle of the cylinder, were used in most cases (see Fig. 10). The effect of the non-uniform pressure left by the detonation wave is shown very strongly in Fig. 14 (Exps. 9 and 11) where there were four evenly spaced detonation points at the ends of the cylinders (at the bottom in the photograph). Even when several detonation points are used there is usually evidence of greater action in the region between detonation points. There are almost always sharply defined lines, along which the detonation waves come together, showing at least a slight etching of the metal and in several cases a strong tendency to shear. This is shown expecially well in Figs. 12 and 13. When shearing rupture occurs it is usually along a surface making an angle of about 45° with a radial plane, which is the direction in which the strain is a simple shear (also in which the shearing strain and stress are a maximum).

It seems likely that fairly uniform collapse can be produced by using a sufficiently large explosive charge; this conclusion follows from the fact that the pressure exerted by the explosive is large compared to the

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strength of the material, and if the shells are given a large enough inward momentum the stresses should play a relatively small part. Experimental evidence for this is shown in Figs. 11, 15, 16, 18 and 19. In Fig. 11, Exp. 1, for example, the steel tube was 3" diameter, $\frac{1}{4}$" wall, with a 3/4" charge of TNT crystals; Exp. 7 was the same except that the charge was $1\frac{1}{2}$" thick. In the first case the tube collapsed more or less uniformly until the wall had thickened to about 5/16", then ruptured into a number of strips which went into an irregular bundle. In the second case the collapse was evidently quite uniform but so violent that the tube bounced out again and fragmented. The thin-walled copper tube of Fig. 15, Exp. 5 is another striking example of the same thing.

In attempting to interpret the data by means of the curves of Figs. 6, 7, only the cases of partial collapse, or else complete collapse without fragmentation could be used. In cases where the collapse was non-uniform, or where rupture occurred, an attempt was still made to estimate the collapse ratio by getting a rough average of the wall thickness. This was done even in the case of Fig. 1, Exp. 1, on the grounds that the work done in the initial thickening of the wall was probably large compared to the work of collapsing the bundle of ruptured strips. The mass ratios $\rho_e h_e / \rho h$ actually used and the ones calculated are listed in Table 3. Five points having $\lambda = .667$ or $.833$ are marked with (*) and plotted in Fig. 6 or 7.

The yielding stress; time of collapse

There is no sound basis for choosing to interpret the data in terms of a yielding stress of 300,000 lb/in^2. This value was quoted to the writer in private conversation as an approximate experimental result for extreme and very rapid deformation, which appeared to be more or less independent of the heat treatment the steel had received. As this value appeared to fit the data for Composition C it was chosen as a reasonable value, although likely to be high. Independent checks of the effective values of s are to

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be made both by calorimetric measurement of the heat of working and by measurements of the rate of collapse.

Two preliminary measurements of the time of collapse, made by a bullet-catching method devised by Streib, for a 3" OD, $\frac{1}{2}$" wall steel cylinder with a $\frac{1}{2}$" charge of Composition C gave times of about 10^{-4} sec. The expected value would be about half this on the basis of 300,000 lb/in^2. These first experimental values should be however essentially upper limits, and further measurements by this and other methods will be the subject of a later report by Streib.

Velocities of projectiles fired with small charges of high explosive

To get some independent information on the relation between terminal velocities and mass ratios, some experiments have been begun by Bradner and Bloch, in which 2" diameter steel projectiles were fired upward with varying charges (confined only by pasteboard and thin wood) of pentolite of the same diameter, pressed to a density 0.45 g/cm^3. Velocities were determined by measuring the time of flight with a stop watch. The data for two projectile sizes are plotted in Fig. 20.

A very rough interpretation of these experiments can be given in terms of the simple one-dimensional theory of Sec. I, if we assume that immediately after detonation the rarefaction wave travels inward from the two free surfaces of the detonated explosive with the same constant velocity. We then assume that the initial pressure p_o acts on the surface of the projectile at any point only until the rarefaction reaches that point, and that the pressure is thereafter negligible. With these simple assumptions we can compute the ratio of the momentum imparted to the projectile to the momentum it should have got if the explosive were free to expand only from the free end surface.

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We get for this ratio

$$P/P_1 = r_e/3l_e \qquad \text{for } r_e < l_e$$
$$= 1 - l_e/r_e + l_e^2/3r_e^2 \qquad \text{for } r_e > l_e,$$

where r_e = radius of projectile and charge, and l_e = length of charge. This factor is applied to the result of the one-dimensional calculation to get the curves of Fig. 20 appropriate to the projectile masses used. Good agreement cannot be expected, but the curves do seem to represent the trend of the experimental data. More complete results will be given in a later report by Bloch and Bradner.

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TABLE 3. SUMMARY OF PRINCIPAL RESULTS

Notation: R_1, R_2 = Initial outer, inner radii; r_1, r_2 = final outer, inner radii

$\lambda = R_2/R_1$

y = "Inner" collapse ratio r_2/R_1

h_e, ρ_e, h, ρ = thicknesses and densities of explosive and cylinder.

		CYLINDER					EXPLOSIVE				
										$\rho_e h_e/\rho h$	
Fig.	Exp. no.	Material	R_1	R_2	λ	y	Material	h_e	ρ_e	used	calc. from y
			in.	in.				in.			
11	1*)	Steel	1.50	1.25	0.833	0.633	TNT	0.75	0.87	0.28	.17
	7[2]	Steel	1.50	1.25	0.833	0 [2]	TNT	1.50	.87	.67	> .40
12	2*)	Steel	1.50	1.00	.667	.553	TNT	.75	.87	.167	.12
	10*)	Steel	1.50	1.00	.667	.23	TNT	1.50	.87	.32	.26
13	3	Steel	2.00	1.00	.500	.408	TNT	1.00	.87	.11	.11
	4	Steel	2.00	1.50	.750	.601	TNT	1.00	.87	.22	.14
14	9[1]	Steel	1.50	.75	.500	.17 [1]	TNT	1.50	.87	.22	--
	11[1]	Steel	1.50	1.00	.667	~.10 [1]	TNT	1.50	.87	.33	--
15	6	Bronze	1.640	1.047	.638	~.27	TNT	1.36	.87	.23	--
	5[2]	Copper	1.750	1.531	.875	0 [2]	TNT	1.25	.87	.56	--
16	13[2]	Steel	1.50	1.00	.667	0 [2]	Comp. C	1.50	1.49	.57	> .2
	14[2]	Steel	1.50	.75	.500	0 [2]	Comp. C	1.50	1.49	.38	> .15
17	18[2]	Steel	2.00	1.00	.500	0 [2]	Comp. C	1.00	1.46	.19	.15
18	26*)	Steel	3.00	2.00	.667	~.37	Comp. C	.75	~1.5	.14	.14
19	21*)	Steel	3.00	2.00	.667	0	Comp. C	1.00	1.59	.20	.20
20	22	Steel	3.00	2.00	.667	0	Comp. C	1.00	~1.5	.19	.20

*) Plotted as an experimental point in Fig. 6 or 7.
1) Detonated from lower end. Measured at section of maximum collapse.
2) Collapsed and fragmented.

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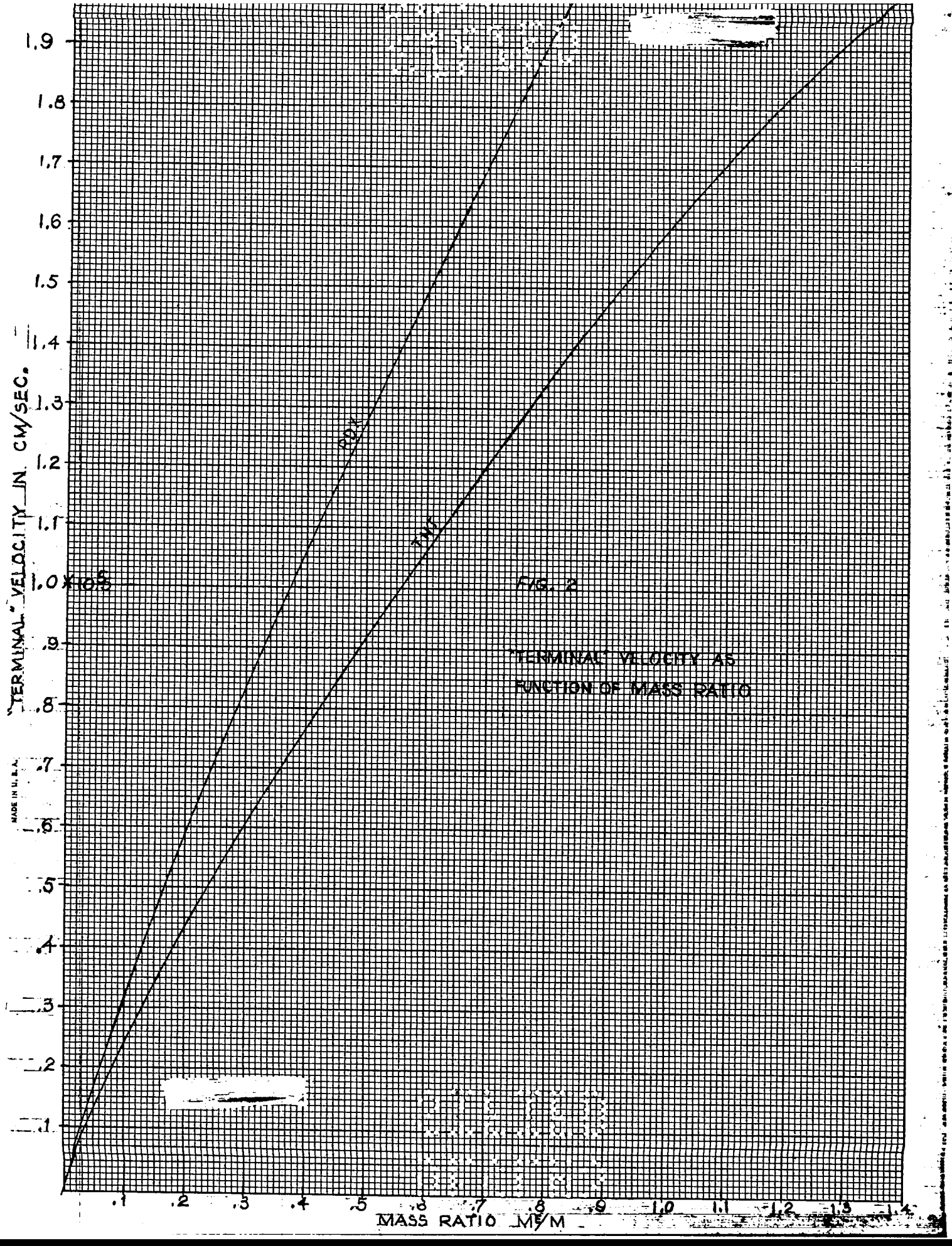


FIG. 2

TERMINAL VELOCITY AS FUNCTION OF MASS RATIO

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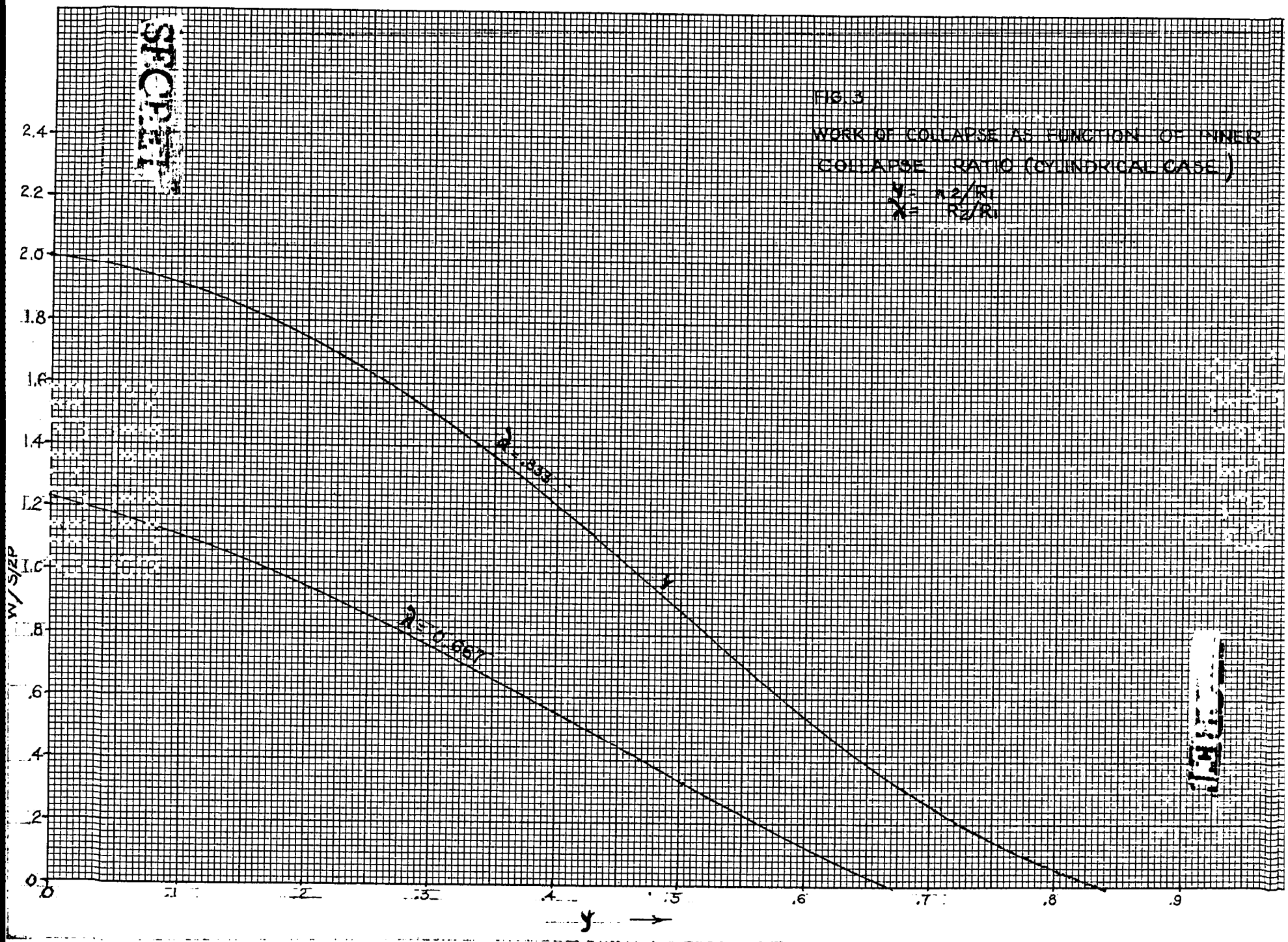
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FIG. 3

WORK OF COLLAPSE AS FUNCTION OF INNER COLLAPSE RATIO (CYLINDRICAL CASE)

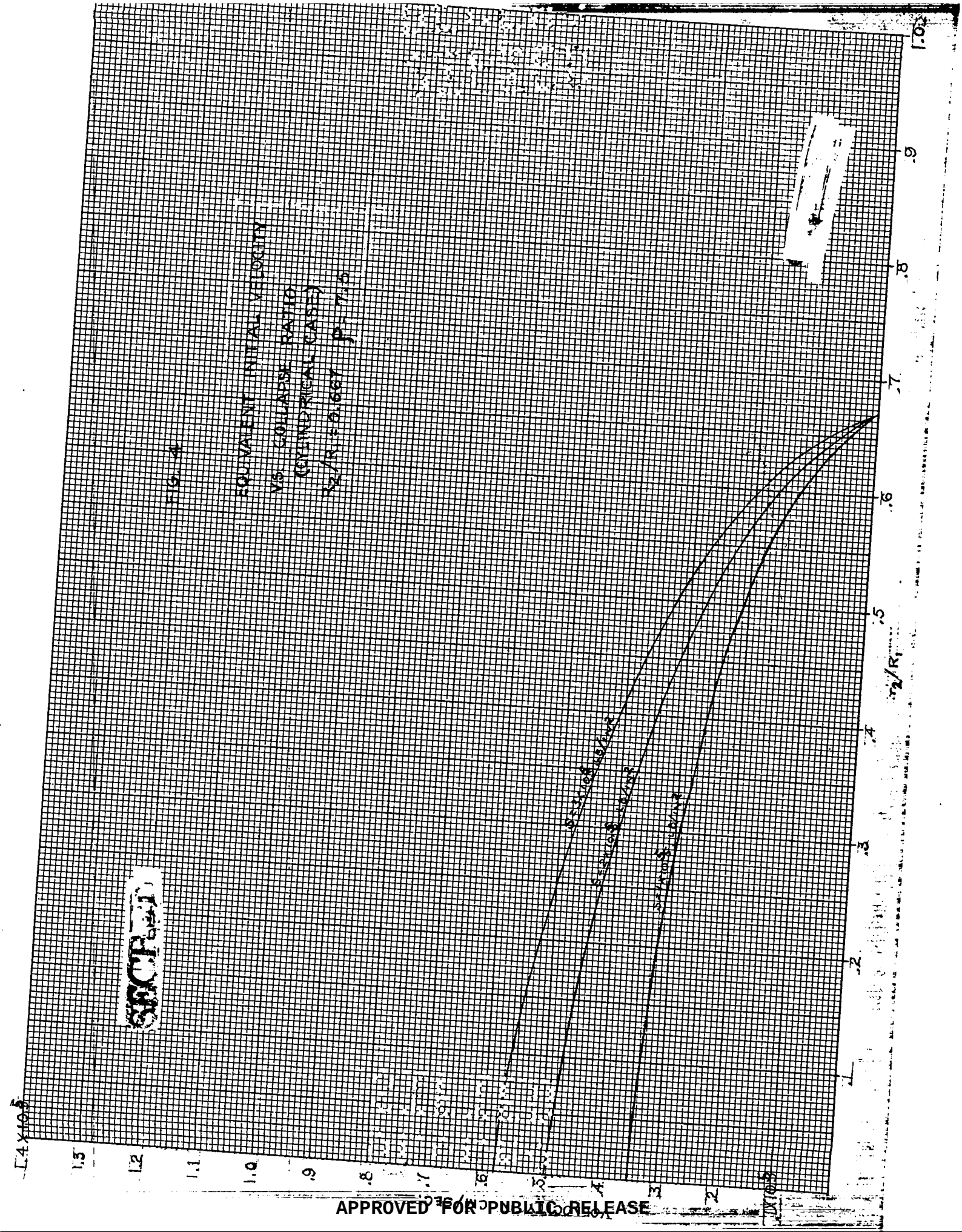
$y = \pi^2/R_1$

$x = R_2/R_1$



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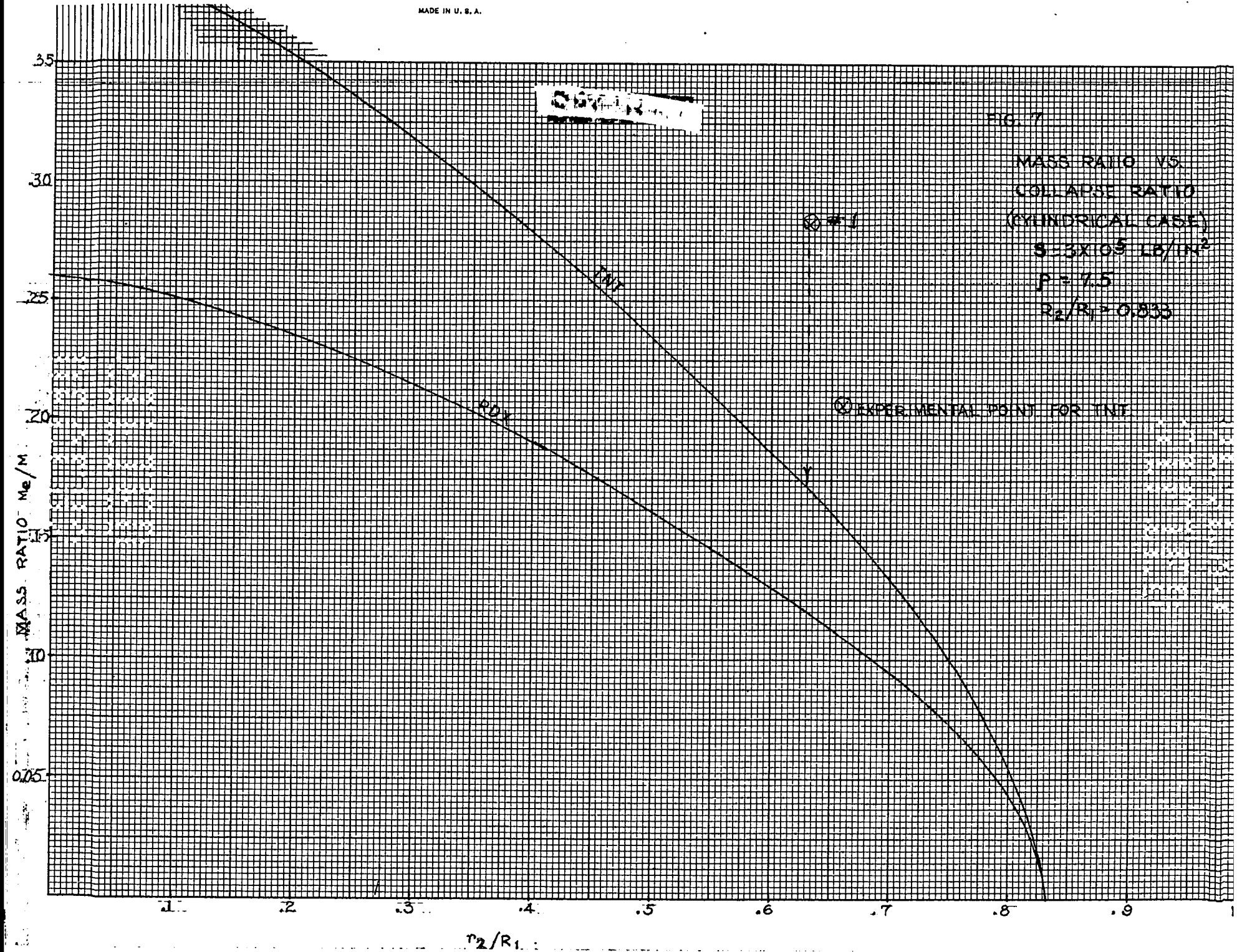


FIG. 7

MASS RATIO VS.
COLLAPSE RATIO
(CYLINDRICAL CASE)
$S = 3 \times 10^5$ LB/IN^2
$\rho = 7.5$
$R_2/R_1 = 0.833$

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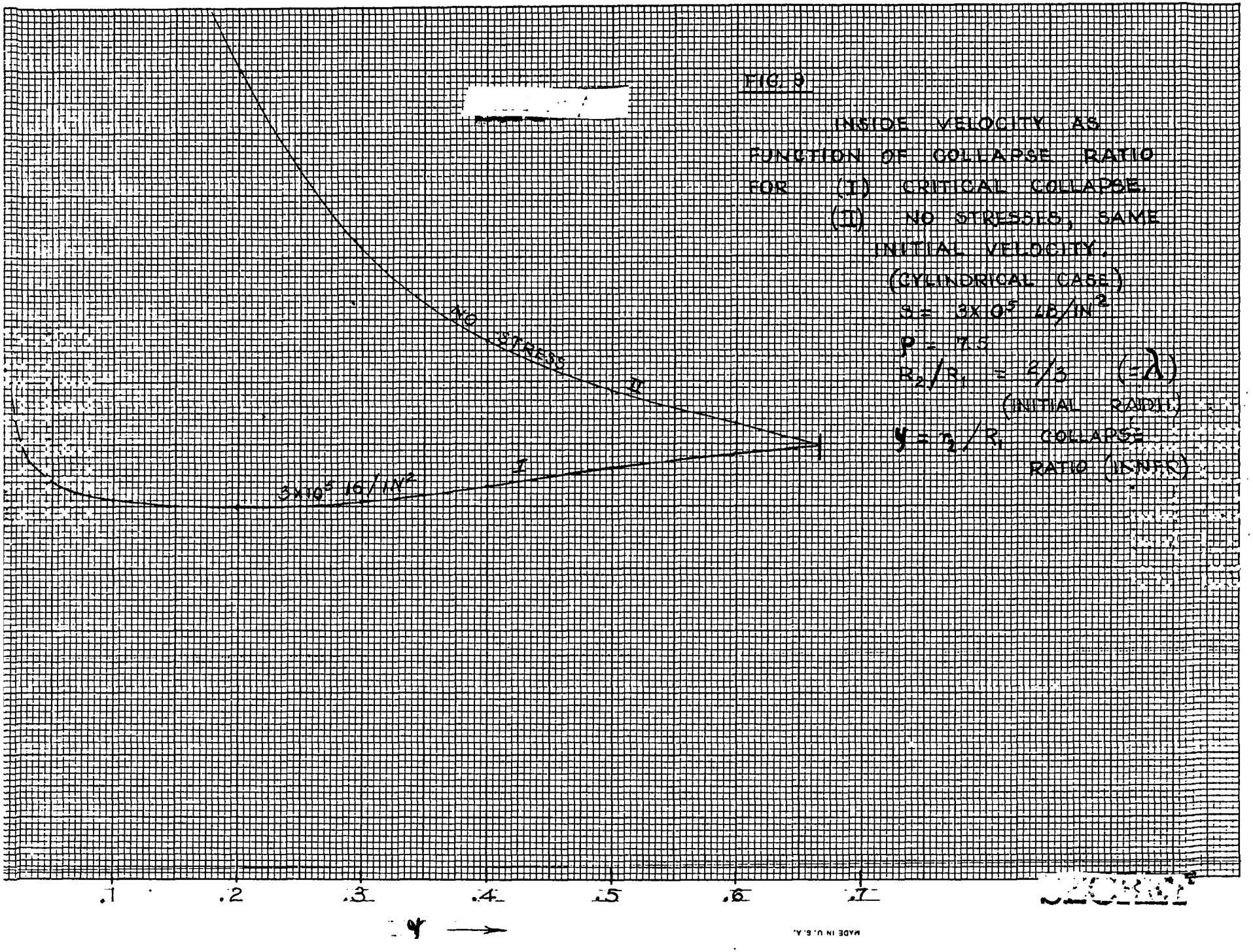


FIG. 9

INSIDE VELOCITY AS FUNCTION OF COLLAPSE RATIO FOR (I) CRITICAL COLLAPSE. (II) NO STRESSES, SAME INITIAL VELOCITY. (CYLINDRICAL CASE)

$S = 3\times10^5$ LB/IN^2

$\rho = 7.5$

$R_2/R_1 = 2/3$ $(=\lambda)$ (INITIAL RADII)

$\psi = r_2/R_1$ COLLAPSE RATIO (RADII)

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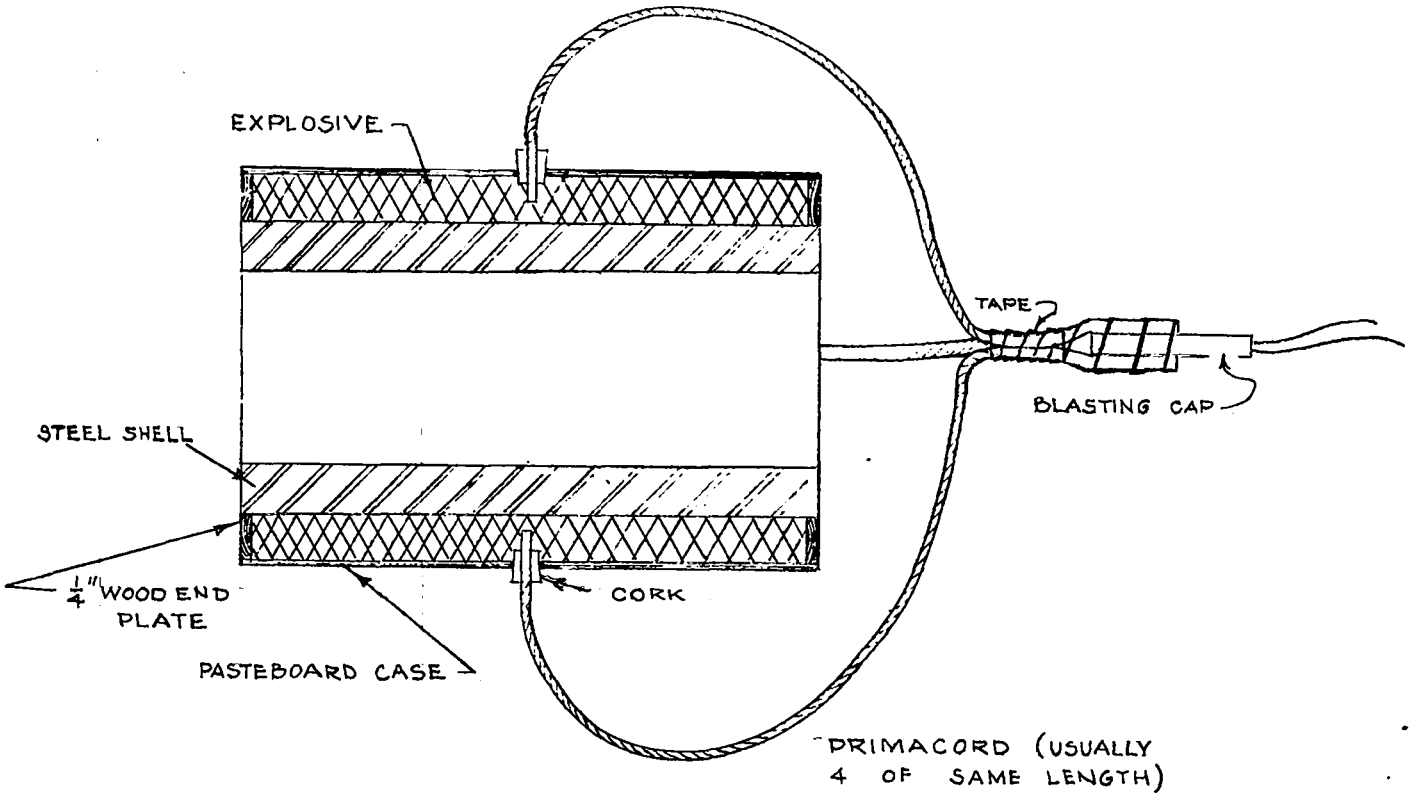


FIG. 10

SECTION OF TYPICAL ASSEMBLY
DRAWN TO SCALE OF EXPERIMENT # 26

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PHOTOGRAPH

The detailed data are given in Table 3. Experiment numbers are marked on the samples in the photographs. In each photograph the original size of the sample is shown by a ring or a complete cylinder. All cylinders are seamless 30-40 carbon steel tubing with a static yield point of about 55000 lb./in^2. Four-point detonation at center unless otherwise stated. Loading density for TNT, 0.87; for Comp. C, about 1.5.

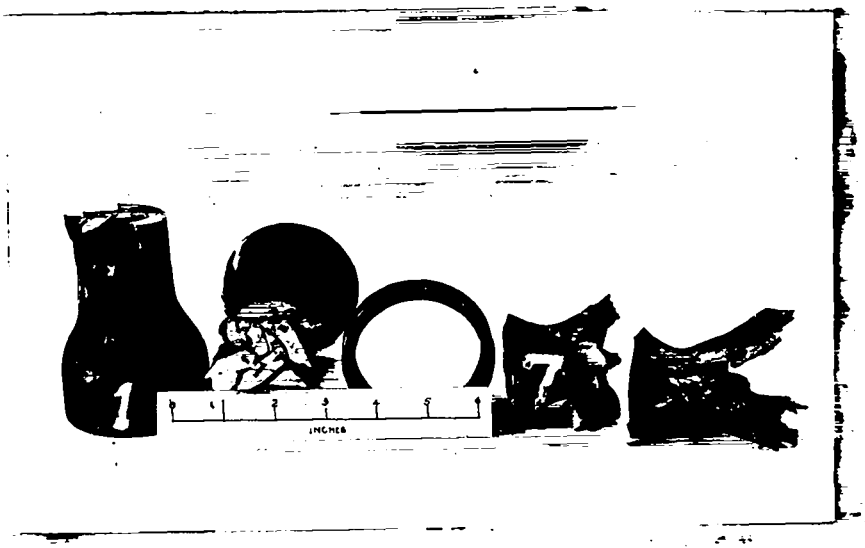


Fig. 11. Exp. 1: 3" OD, ¼" wall, 8" long
TNT ½" thick, 6" long.

The boundary of the explosive charge can be seen etched on the cylinder.

Exp. 7: Same except TNT 1½" thick, 7½" long.

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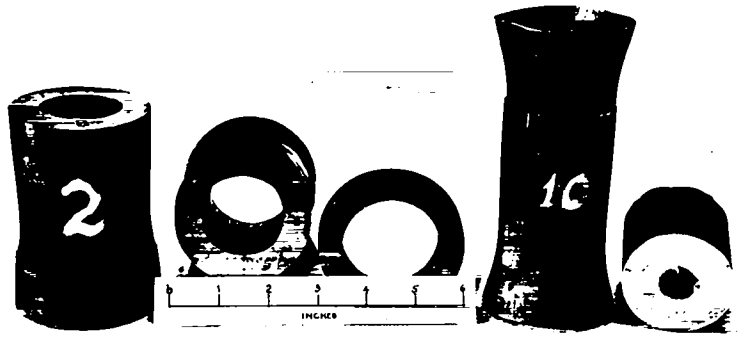


Fig. 12. No. 2: 3" OD, $\frac{1}{8}$" wall, 8" long
TNT $\frac{3}{4}$" thick, 6" long

No. 10: Same except TNT $1\frac{1}{2}$" thick, $7\frac{1}{2}$" long
No. 2 increased in length about $\frac{1}{4}$" and No. 10 about $\frac{3}{4}$"

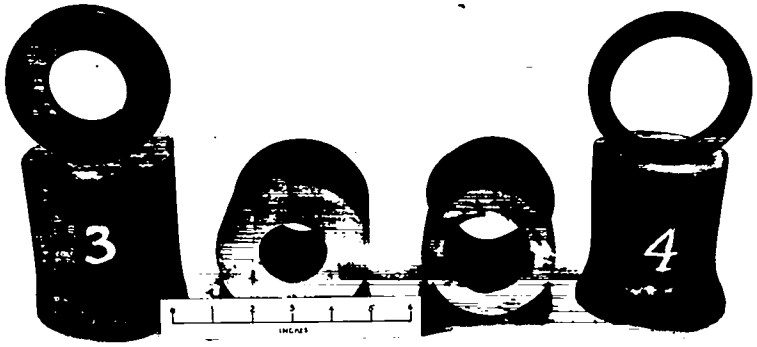


Fig. 13. Exp. 3: 4" OD, 1" wall, 8" long
TNT, 1" thick, $7\frac{1}{2}$" long

Exp. 4: 4" OD, $\frac{1}{8}$" wall, 8" long
TNT, 1" thick, $7\frac{1}{2}$" long
Shearing rupture is shown along lines where detonation waves meet.

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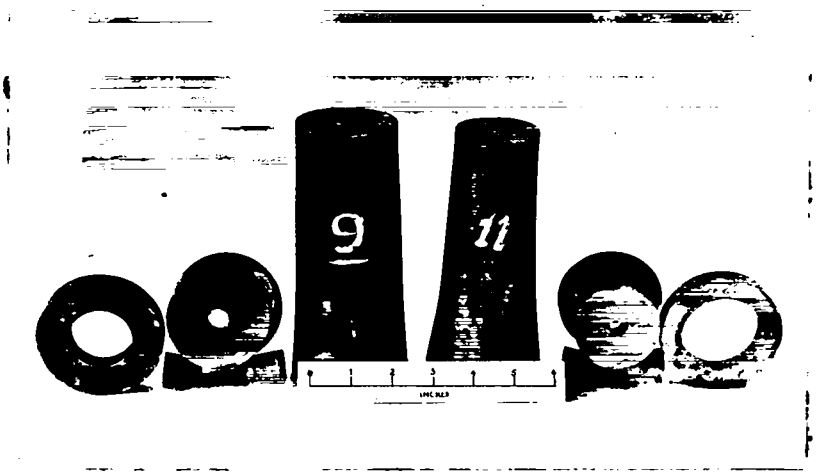


Fig. 14. Exp. 9: 3" OD, $\frac{3}{4}$" wall, 8" long
TNT, $1\frac{1}{2}$" thick, $7\frac{1}{2}$" long

Exp. 11: 3" OD, $\frac{1}{2}$" wall, 8" long, same charge

Both detonated from 4 points at lower end in photograph

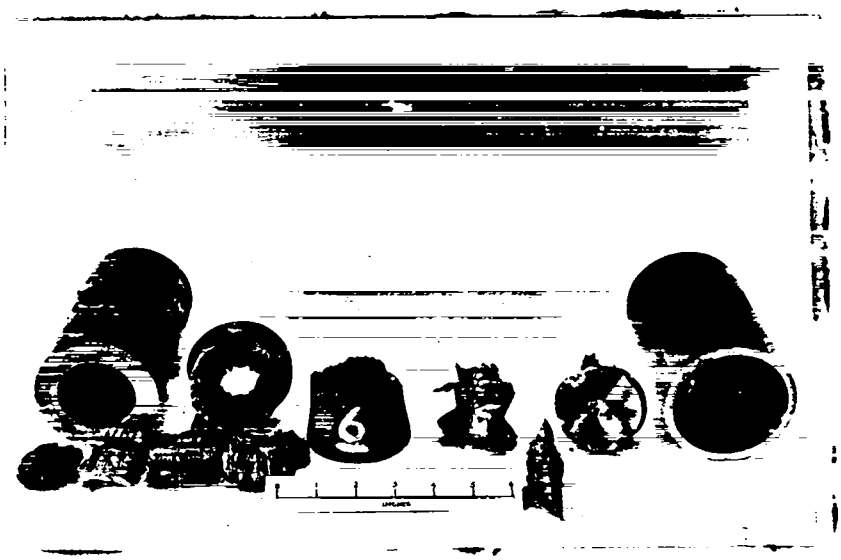


Fig. 15. Exp. 6: Bronze, 3.281" OD, 0.593" wall, 6" long
TNT, 1.36" thick, $5\frac{1}{2}$" long

Exp. 5: Copper, $3\frac{1}{8}$" OD, 7/32" wall, 6" long
TNT, $1\frac{1}{4}$" thick, $5\frac{1}{2}$" long

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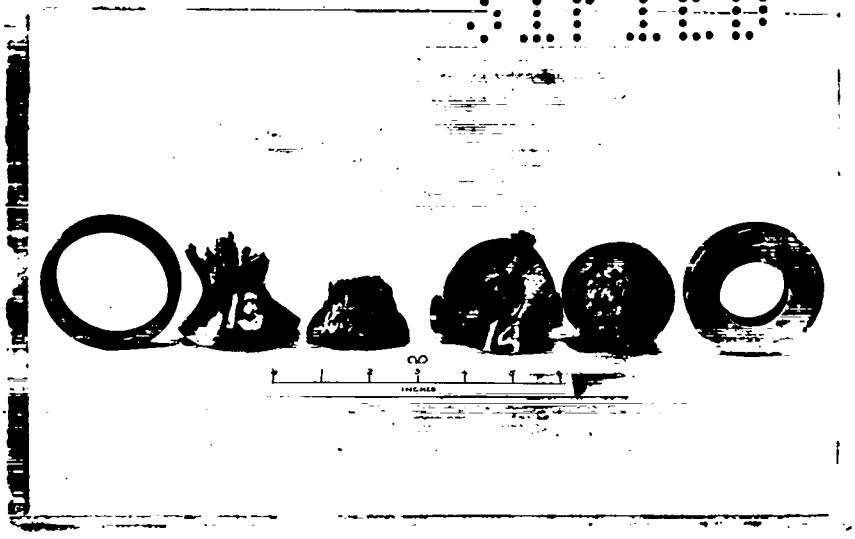


Fig. 16. Exp. 13: 3" OD, $\frac{1}{2}$" wall, 8" long
Comp. C, $1\frac{1}{2}$" thick, $7\frac{1}{2}$" long
Cf. Fig. 11, note uniform collapse when excessive charge is used

Exp. 14: 3" OD, $\frac{3}{4}$" wall, 8" long
Comp. C, $1\frac{1}{2}$" thick, $7\frac{1}{2}$" long
Plastic flow can be seen through end of cylinder

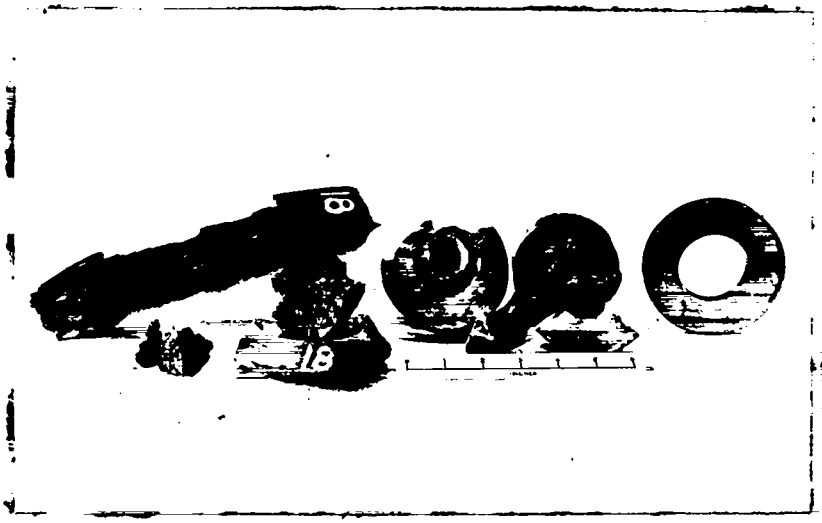


Fig. 17. Exp. 18: 4" OD, 1" wall, 12" long
Comp. C, 1" thick, $11\frac{1}{2}$" long. The pinching off of the ends with an approximately triangular section is typical. The long fragments show complete collapse before fragmentation. The somewhat porous appearance of the fragments is probably indicative of the release of a considerable ~~energy stored in elastic~~ compression.

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Fig. 18. Exp. 26: 6" OD, 1" wall, 12 3/16" long
Comp. C, ¾" thick, 12 11/16" long

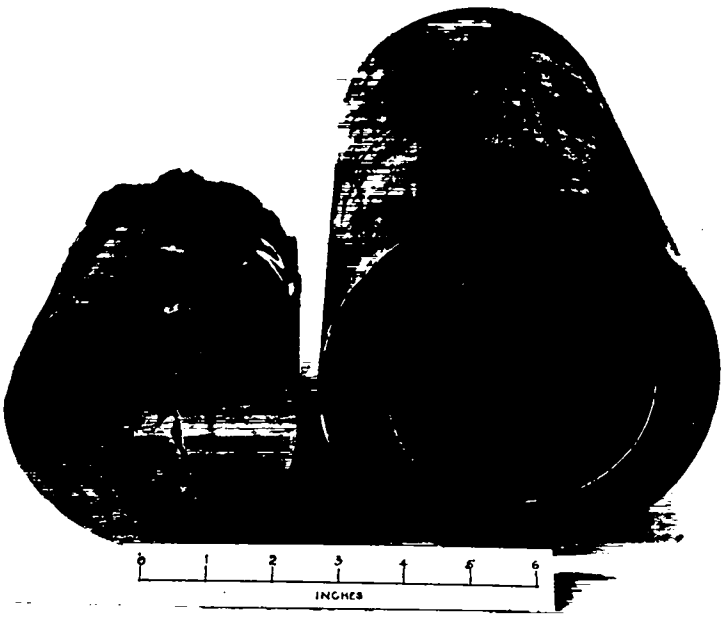
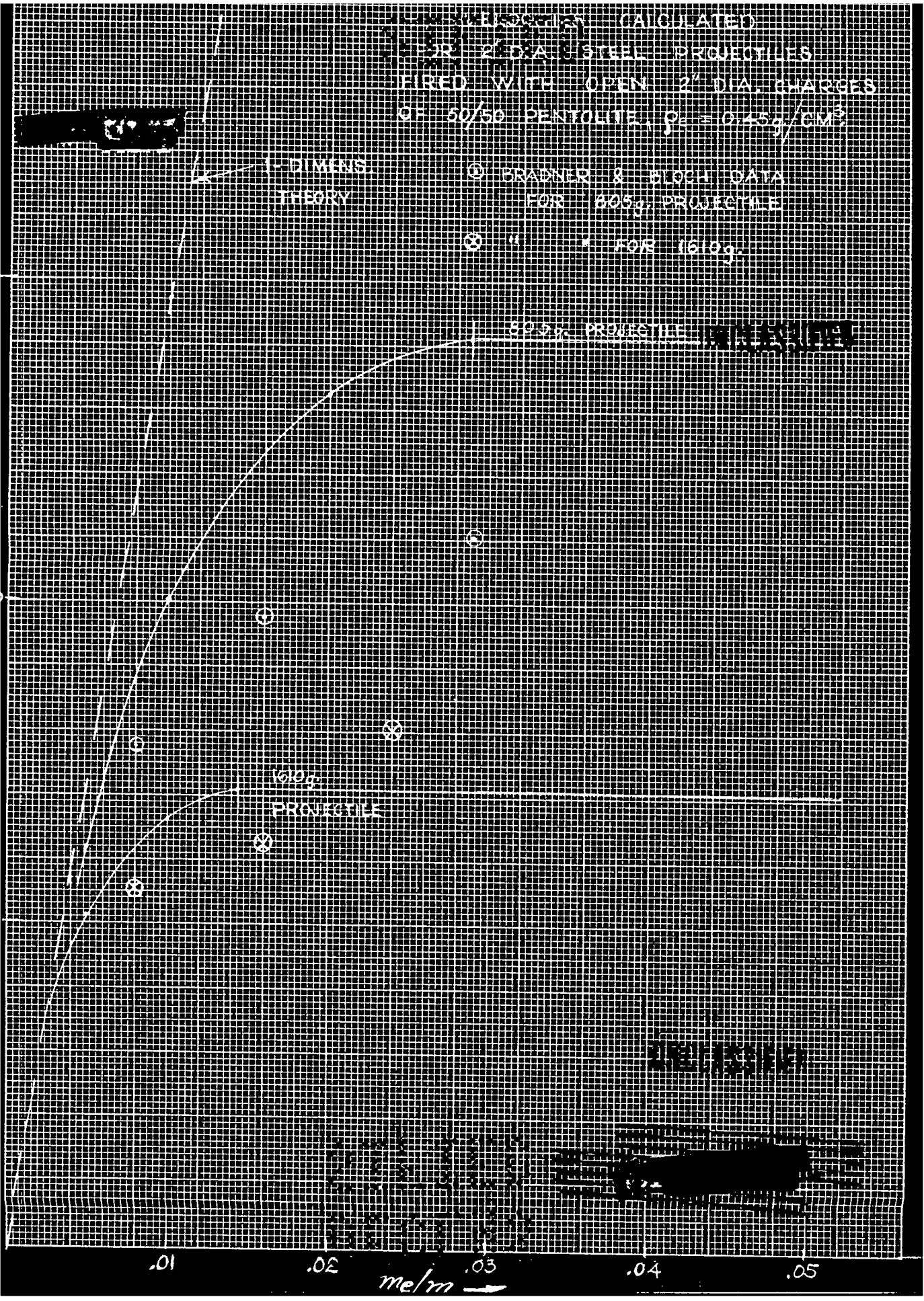


Fig. 19. Exp. 21: 6" OD, 1" wall 12" long
Comp. C, 1" thick, 12" long

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THE LOS ALAMOS PRIMER

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The following notes are based on a set of five lectures given by R. Serber during the first two weeks of April 1943, as an "indoctrination course" in connection with the starting of the Los Alamos Project. The notes were written up by E. U. Condon.

Bob Serber

1. Object

The object of the project is to produce a practical military weapon in the form of a bomb in which the energy is released by a fast neutron chain reaction in one or more of the materials known to show nuclear fission.

2. Energy of Fission Process

The direct energy release in the fission process is of the order of 170 MEV per atom. This is considerably more than 10^7 times the heat of reaction per atom in ordinary combustion processes.

This is $170 \cdot 10^6 \cdot 4.8 \cdot 10^{-10}/300 = 2.7 \cdot 10^{-4}$ erg/nucleus. Since the weight of 1 nucleus of 25 is $3.88 \cdot 10^{-22}$ gram/nucleus the energy release is

$$7 \cdot 10^{17} \text{ erg/gram}$$

The energy release in TNT is $4 \cdot 10^{10}$ erg/gram or $3.6 \cdot 10^{16}$ erg/ton. Hence

$$1 \text{ kg of } 25 \approx 20000 \text{ tons of TNT}$$

3. Fast Neutron Chain Reaction

Release of this energy in a large scale way is a possibility because of the fact that in each fission process, which requires a neutron to produce it, two neutrons are released. Consider a very great mass of active material, so great that no neutrons are lost through the surface and assume the material so pure that no neutrons are lost in other ways than by fission. One neutron released in the mass would become 2 after the first fission, each of these would produce 2 after they each had produced fission so in the nth generation of neutrons there would be 2^n neutrons available.

Since in 1 kg. of 25 there are $5 \cdot 10^{25}$ nuclei it would require about $n = 80$ generations ($2^{80} \approx 5 \cdot 10^{25}$) to fish the whole kilogram.

While this is going on the energy release is making the material very hot, developing great pressure and hence tending to cause an exposion.

In an actual finite setup, some neutrons are lost by diffusion out through the surface. There will be therefore a certain size of say a sphere for which the surface losses of neutrons are

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on the density. As the reaction proceeds the material tends to expand, increasing the required minimum size faster than the actual size increases.

The whole question of whether an effective explosion is made depends on whether the reaction is stopped by this tendency before an appreciable fraction of the active material has fished.

Note that the energy released per fission is large compared to the total binding energy of the electrons in any atom. In consequence even if but $\frac{1}{2}\%$ of the available energy is released the material is very highly ionized and the temperature is raised to the order of $40 \cdot 10^6$ degrees. If 1% is released the mean speed of the nuclear particles is of the order of 10^8 cm/sec. Expansion of a few centimeters will stop the reaction, so the whole reaction must occur in about $5 \cdot 10^{-8}$ sec otherwise the material will have blown out enough to stop it.

Now the speed of a 1 MEV neutron is about $1.4 \cdot 10^9$ cm/sec and the mean free path between fissions is about 13 cm so the mean time between fissions is about 10^{-8} sec. Since only the last few generations will release enough energy to produce much expansion, it is just possible for the reaction to occur to an interesting extent before it is stopped by the spreading of the active material.

Slow neutrons cannot play an essential role in an explosion process since they require about a microsecond to be slowed down in hydrogenic materials and the explosion is all over before they are slowed down.

4. Fission Cross-sections

The materials in question are $U_{92}^{235} = 25$, $U_{92}^{238} = 28$ and element $94^{239} = 49$ and some others of lesser interest.

Ordinary uranium as it occurs in nature contains about 1/140 of 25, the rest being 28 except for a very small amount of 24.

The nuclear cross-section for fission of the two kinds of U and of 49 is shown roughly in Fig. 1 where σ_f is plotted against the log of the incident neutron's energy. We see that 25 has a cross-section of about $\sigma_f \approx 1.5 \cdot 10^{-24}$ cm^2 for neutron energies exceeding 0.5 MEV and rises to much higher values at low neutron energies ($\sigma_f = 640 \cdot 10^{-24}$ cm^2 for thermal neutrons). For 28 however a threshold energy of 1 MEV occurs below which $\sigma_f = 0$. Above the threshold σ_f is fairly constant and equal to $0.7 \cdot 10^{-24}$ cm^2.

(Fig. 1 on next page)

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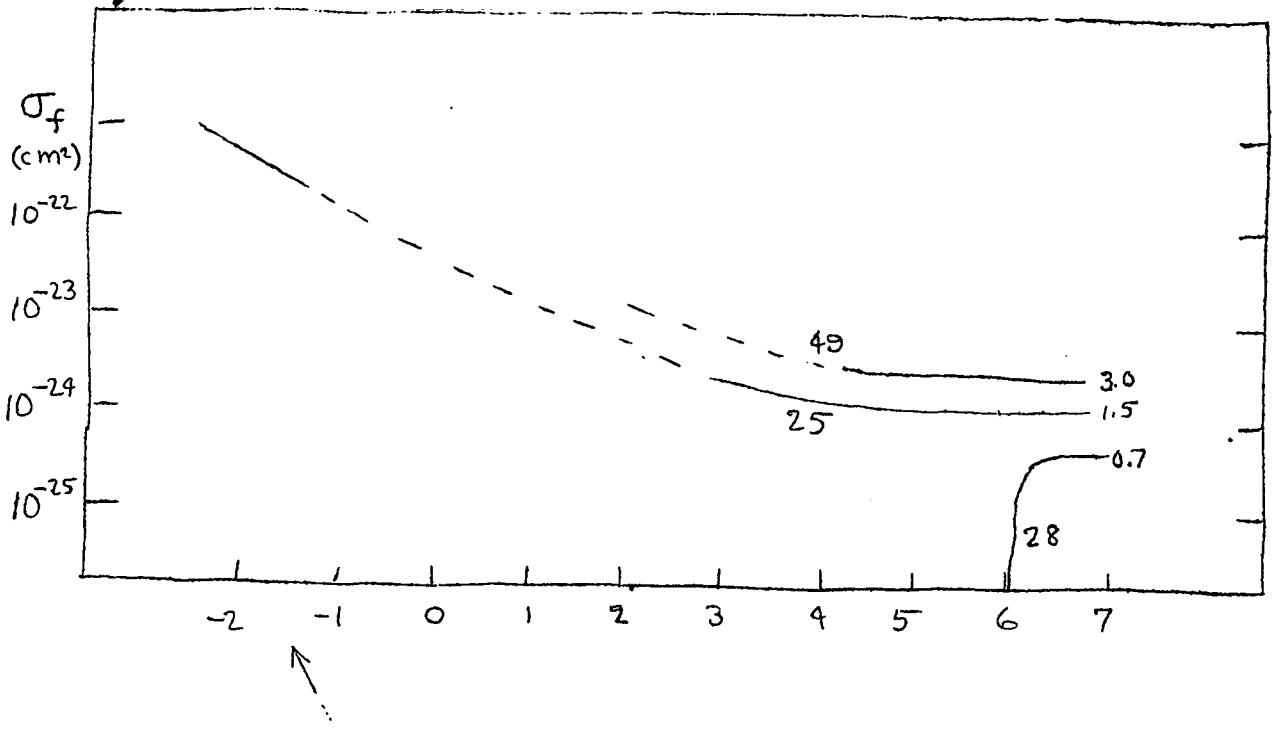
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Fig. 1.



(thermal) log neutron energy in EV.

5. Neutron Spectrum

In Fig. 2 is shown the energy distribution of the neutrons released in the fission process. The mean energy is about 2 MEV but an appreciable fraction of the neutrons released have less than 1 MEV of energy and so are unable to produce fission in 28.

One can give a quite satisfactory interpretation of the energy distribution in Fig. 2 by supposing it to result from evaporation of neutrons from the fission product nuclei with a temperature of about $\frac{1}{2}$ MEV. Such a Maxwellian velocity distribution is to be relative to the moving fission product nuclei giving rise to a curve like Fig. 2.

(Fig. 2 on next page)

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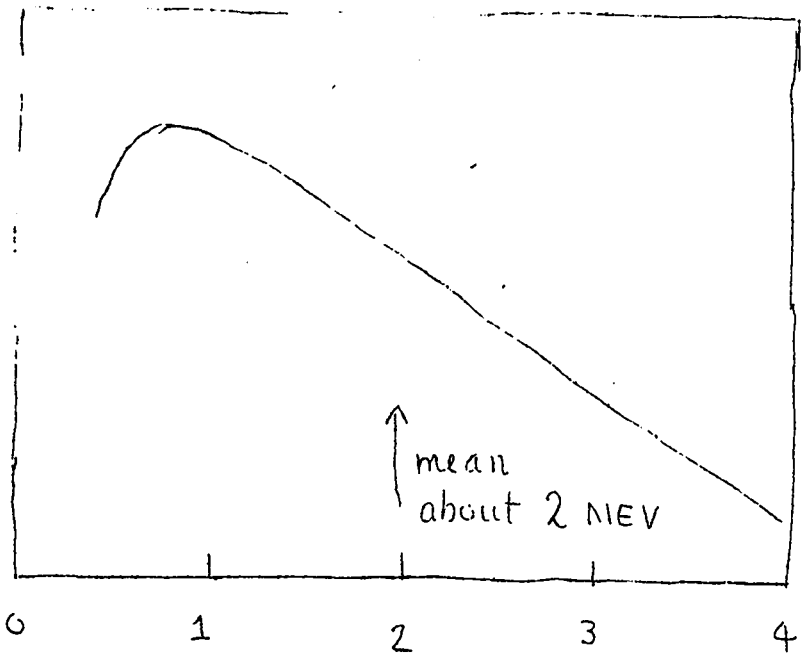
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Fig. 2



neutron energy in MEV

6. Neutron number

The average number of neutrons produced per fission is denoted by ν. It is not known whether ν has the same value for fission processes in different materials, induced by fast or slow neutrons or occurring spontaneously.

The best value at present is

$$\nu = 2.2 \pm 0.2$$

although a value $\nu = 3$ has been reported for spontaneous fission.

7. Neutron capture

When neutrons are in uranium they are also caused to disappear by another process represented by the equation

$$28 + n \rightarrow 29 + \gamma$$

The resulting element 29 undergoes two successive β transformations into elements 39 and 49. The occurrence of this process in 28 acts to consume neutrons and works against the possibility of a fast neutron chain reaction in material containing 28.

It is this series of reactions, occurring in a slow neutron fission pile, which is the basis of a project for large scale production of element 49.

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8. Why ordinary U is safe

Ordinary U, containing only 1/140 of 25, is safe against a fast neutron chain because, (a) only 3/4 of the neutrons from a fission have energies above the threshold of 28, (b) only $\frac{1}{4}$ of the neutrons escape being slowed below 1 MEV, the 28 threshold before they make a fission.
So the effective neutron multiplication number in 28 is

$$\nu \approx 3/4 \times 1/4 \times 2.2 = 0.4$$

Evidently a value greater than 1 is needed for a chain reaction. Hence a contribution of at least 0.6 is needed from the fissionability of the 25 constituent. One can estimate that the fraction of 25 must be increased at least 10-fold to make an explosive reaction possible.

9. Material 49

As mentioned above this material is prepared from the neutron capture reaction in 28. So far only microgram quantities have been produced so bulk physical properties of this element are not known. Also its ν value has not been measured. Its σ_f has been measured and found to be about twice that of 25 over the whole energy range. It is strongly α-radioactive with a half-life of about 20000 years.

Since there is every reason to expect its ν to be close to that for U and since it is fissionable with slow neutrons it is expected to be suitable for our problem and another project is going forward with plans to produce it for us in kilogram quantities.

Further study of all its properties has an important place on our program as rapidly as suitable quantities become available.

10. Simplest Estimate of Minimum Size of Bomb

Let us consider a homogeneous material in which the neutron number is ν and the mean-time between fissions is τ. In Sec. 3 we estimated $\tau = \cdot\ 10^{-8}$sec. for uranium. Then if N is the number of neutrons in unit volume we have

$$\dot{N} + \operatorname{div} \underline{j} = \frac{\nu - 1}{\tau} N$$

The term on the right is the net rate of generation of neutrons in unit volume. The first term on the left is the rate of increase of neutron density. In the second term on the left $\underline{j}$ is the net diffusion current stream of the neutrons (net number of neutrons crossing 1 cm^2 in 1 sec across a plane oriented in such a way that this net number is maximum).

In ordinary diffusion theory (which is valid only when all dimensions of boundaries are large compared to the mean free path of the diffusing particles - a condition not fulfilled in our case) the diffusion current is proportional to the gradient of N,

$$\underline{j} = -D \operatorname{grad} N$$

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where D is the diffusion coefficient (cm^2/sec).

Hence we have

$$\dot{N} = D\Delta N + \left(\frac{\nu-1}{\tau}\right)N$$

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Assume a solution whose time dependence is of the form

$$N = N_1(x,y,z)\, e^{\nu' t/\tau}$$

where ν' is called the "effective neutron number". The equation to be satisfied by N_1 is

$$\Delta N_1 + \frac{-\nu'+\nu-1}{D\tau} N_1 = 0$$

together with a boundary condition. In the simple case in which we are dealing with a sphere of radius R, we may suppose that N_1 is spherically symmetric.

At $r=R$ we would have, on simple theory $N_1 = 0$. (In point of fact $N_1 > 0$ due to the effect of the mean free path's not being small compared with R, but this will not be considered here). For spherical symmetry the equation for N_1 has the solution

$$N_1(r) = \frac{\sin(\pi r/R)}{r}$$

provided that ν' has the value

$$\nu' = (\nu-1) - \pi^2 D\tau/R^2.$$

This shows that in an infinitely large sphere the neutron density would build up with the time constant $(\nu-1)/\tau$. Smaller spheres build up less rapidly. Any sphere so small that $\nu' < 0$ is one for which the neutrons leak out the surface so rapidly that an initial density will die out rather than build up. Hence the critical radius is given by

$$R_c^2 = \frac{\pi^2 D\tau}{\nu-1} \qquad \nu'=0$$

Now D is given by $D = \lambda v/3$ where λ is the transport mean free path, $\lambda = 1/n\sigma_t$, n is the number of nuclei per cc and

$$\sigma_t = \left[\sigma_f + \int\int \sigma_s(1-\cos\theta)\,d\omega\right]$$

which brings out the reason for measurements of the angular scattering of neutrons in U. In metallic U we have

$$\sigma_t = 4\cdot 10^{-24}\ cm^2.$$

which, for a density of 19 gm/cm^3, gives $\lambda = 5$ cm.
Also

$$\tau = \frac{1}{n\sigma_f v} = \frac{\ell}{v}\frac{\sigma_t}{\sigma_f} \quad \text{so } \pi^2 D\tau = \frac{\pi^2}{3}\ell^2\frac{\sigma_t}{\sigma_f} = 220.$$

Therefore

$$R_c^2 = \frac{220}{1.3} = 183 \text{ and } R_c = 13.5\ cm.$$

The critical volume is therefore $10.5\cdot 10^3$ cm^3 giving a critical mass of 200 kilograms.

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Exercise: Show that if the gadget has the shape of a cube, $0<x<a$, $0<y<a$, $0<z<a$, that the critical value of a is given by

$$a = \sqrt{3}\, R_c$$

Hence the critical mass for a cubical shape is $3^{5/2}/4\pi = 1.24$ times as great as for a sphere.

The value of the critical mass is, however, considerably overestimated by the elementary diffusion theory. The more exact diffusion theory allowing for the long free path drops Rc by a factor about 2/3 giving

$$R_c \sim 9\ \text{cm} \qquad M_c \sim 60\ \text{kg of 25.}$$

The elementary treatment just given indicates the dependence of M_c on the principal constants

$$M_c \sim \frac{1}{\rho^2}\left[\frac{1}{\sigma_f \sigma_t (\nu-1)}\right]^{3/2}$$

where ρ is the density. For $R \neq R_c$ we have the time dependence of neutron multiplication given by

$$e^{(\nu-1)t\left[1-\left(\frac{R_c}{R}\right)^2\right]/\tau}$$

Hence for a sphere of twice the critical mass the time constant, for multiplication of neutron density by e is 2.4×10^{-8} sec.

11. Effect of Tamper

If we surround the core of active material by a shell of inactive material the shell will reflect some neutrons which would otherwise escape. Therefore a smaller quantity of active material will be enough to give rise to an explosion. The surrounding case is called a tamper.

The tamper material serves not only to retard the escape of neutrons but also by its inertia to retard the expansion of the active material. (The retardation provided by the tensile strength of the case is negligible.) For the latter purpose it is desirable to use the densest available materials (Au, W, Re, U). Present evidence indicates that for neutron reflecting properties also, one cannot do better than use these heavy elements. Needless to say, a great deal of work will have to be done on the properties of tamper materials.

We will now analyze the effect of tamper by the same approximate diffusion theory that was used in the preceding section. Let D' be the diffusion coefficient for fast neutrons in the tamper material and suppose the lifetime of a neutron in the tamper is α/τ. Here $\alpha = n'\sigma'_{cap}/n\sigma_f$, with n' the nuclear density of the tamper and σ'_{cap} its capture cross-section. If the tamper material is itself fissionable (U tamper) the absorption coefficient is reduced by a factor $(1-\nu_t)$, with ν_t the number of neutrons produced per capture.

At the boundary between active material and tamper, the diffusion stream of neutrons must be continuous so

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$$D\left(\frac{\partial N}{\partial r}\right)_{active} = D'\left(\frac{\partial N}{\partial r}\right)_{tamper}$$

In the tamper the equation for neutron density is

$$\dot{N} = D'\triangle N - \frac{\alpha}{T}N$$

or for the spatial dependence,

$$\triangle N_1 - \frac{\nu' + \alpha}{D'T} N_1 = 0$$

As an easy special case suppose the tamper has the same neutron diffusion coefficient as the active material (i.e. the same mean free path) but has no absorption, so $\alpha = 0$. Then under critical conditions ($\nu' = 0$) we have

$$N_1 = A/r + B$$

in the tamper material and

$$N_1 = \frac{\sin kr}{r}$$

in the active material.

At the outer boundary of the tamper, $r = R'$, we must have $N_1 = 0$ hence

$$N_1 = A\left(\frac{1}{r} - \frac{1}{R'}\right)$$

On each side of the boundary $r = R$ between active material and tamper material, the slopes must be equal so, equating the densities and slopes on both sides of the boundary we find the following equation to determine k,

$$kR\cos kR + \frac{R/R'}{1 - R/R'}\sin kR = 0$$

In the limit of a very large tamper radius $R' \to \infty$ this requires that

$$k = \pi/2R$$

which is just half the value it had in the case of the untampered gadget. Hence the critical mass needed is <u>one-eighth</u> as much as for the bare bomb.

Actually on better theory the improvement is not as great as this because the edge effect (correction for long free path) is not as big in this case as in the bare bomb. Hence the improvement of non-absorptive equal diffusion tamper over the critical mass, both handled by more accurate diffusion theory only turns out to be a factor of <u>four</u> instead of <u>eight</u>.

<u>Exercise:</u>

Consider a non-absorptive tamper material for which the diffusion coefficient D' is small compared to D. In the limit if $D' = 0$, no neutrons could escape from the active material by diffusion, so the critical radius would vanish and <u>any</u> amount of active core would be explosive.

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To get an idea of the improvement obtainable from tamper material of shorter mean free path than the active material show that if $D' = \frac{1}{2}D$ then the critical mass is 1/2.40 times what it is in the case of thick tamper ($R' = \infty$) if $D' = D$. From this we see that it would be very much worth while to find tamper materials of low diffusion coefficient.

(It turns out that $\chi = kR$ is a root of

$$\chi \cos \chi = (1 - D'/D) \sin \chi$$

which is 1.17 approximately when $D'/D = 0.5$.)

If the tamper material is absorptive then the neutron density in it will fall off like e^{-kr}/r instead of 1/r which tends to make the critical mass greater than if the tamper did not absorb.

The distance the neutrons get into the tamper is $1/k = \ell' \sqrt{\frac{s}{3(1-\nu_t)}}$ where ℓ' is the mean free path and s the number of collisions before capture. Guessing $s \sim 20$ this gives, with $\ell' = 5$ cm, an effective tamper thickness $\sim$ 13cm. For a U tamper $\nu_t \sim 0.6$, and the effective thickness is raised to 17 cm. These figures give an idea of the tamper thickness actually required; the weight of the tamper is about a ton.

For a normal U tamper the best available calculations give R_c = 6 cm and M_c = 15 Kg of 25 while with Au tamper M_c = 22 kg of 25.

The critical mass for 49 might be, because of its larger fission cross section, less than that of 25 by about a factor 3. So for 49

M_c = 5 Kg for U tamper

M_c = 7.5 Kg for Au tamper.

These values of critical masses are still quite uncertain, particularly those for 49. To improve our estimates requires a better knowledge of the properties of bomb materials and tamper: neutron multiplication number, elastic and inelastic cross sections, overall experiments on tamper materials. Finally however, when materials are available, the critical masses will have to be determined by actual test.

12. Damage

Several kinds of damage will be caused by the bomb.

A very large number of neutrons is released in the explosion. One can estimate a radius of about 1000 yards around the site of explosion as the size of the region in which the neutron concentration is great enough to produce severe pathological effects.

Enough radioactive material is produced that the total activity will be of the order of 10^6 curies even after 10 days. Just what effect this will have in rendering the locality uninhabitable depends greatly on very uncertain factors about the way in

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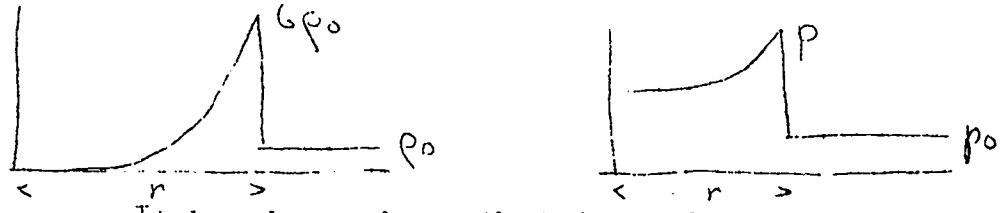
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which this is dispursed by the explosion. However the total amount of radioactivity produced, as well as the total number of neutrons, is evidently proportional just to the number of fission processes, or to the total energy released.

The mechanical explosion damage is caused by the blast or shock wave. The explosion starts acoustic waves in the air which travel with the acoustic velocity, c, superposed on the velocity u of the mass motion with which material is convected out from the center. Since $c \sim \sqrt{T}$ where T is the absolute temperature and since both u and c are greater farther back in the wave disturbance it follows that the back of the wave overtakes the front and thus builds up a sharp front. This is essentially discontinuous in both pressure and density.



It has been shown that in such a wave front the density just behind the front rises abruptly to six times its value just ahead of the front. In back of the front the density falls down essentially to zero.

If E is the total energy released in the explosion it has been shown that the maximum value of the pressure in the wave front varies as

$$p \sim E/r^3$$

the maximum pressure varying as $1/r^3$ instead of the usual $1/r^2$ because the width of the strongly compressed region increases proportionally to r.

This behavior continues as long as p is greater than about 2 atmospheres. At lower pressures there is a transition to ordinary acoustic behavior the width of the pulse no longer increasing.

If destructive action may be regarded as measured by the maximum pressure amplitude, it follows that the radius of destructive action produced by an explosion varies as $\sqrt[3]{E}$. Now in a $\frac{1}{2}$ ton bomb, containing $\frac{1}{4}$ ton of TNT the destructive radius is of the order of 150 feet. Hence in a bomb equivalent to 100000 tons of TNT (or 5 kg of active material totally converted) one would expect a destructive radius of the order of $\sqrt[3]{400000} \times 150 = 1.1 \times 10^4$ feet or about 2 miles.

This points roughly to the kind of results which may be expected from a device of the kind we hope to make. Since the one factor that determines the damage is the energy release, our aim is simply to get as much energy from the explosion as we can. And since the materials we use are very precious, we are constrained to do this with as high an efficiency as is possible.

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13. Efficiency

As remarked in Sec. 3, the material tends to blow apart as the reaction proceeds, and this tends to stop the reaction. In general then the reaction will not go to completion in an actual gadget. The fraction of energy released relative to that which would be released if all active material were transformed is called the efficiency.

Let R_{co} = critical radius figured for normal density ρ_o, also R_o initial radius and R = radius at a particular instant. Assume homogeneous expansion. Then the density when expanded is

$$\rho = \rho_o (R_o / R)^3$$

and the critical radius R_c figured with the actual density ρ is

$$R_c = R_{co} (\rho_o / \rho)$$

The reaction will proceed until expansion has gone so far that $R_c = R$. Therefore the radius R at which expansion stops is given by

$$R / R_o = \sqrt[3]{R_o / R_{co}}$$

Since the ratio of R_o / R_{co} is equal to the cube root of the ratio of M_o, the actual active mass, to M_c the critical mass we see that

$$R / R_o = \sqrt[3]{M_o / M_{co}}$$

and therefore a gadget having twice the critical mass will expand to a radius only $\sqrt[3]{2} = 1.12$ times its original radius before the reaction stops.

The next problem is to find a simple expression for the time taken for this expansion to occur, since we already know how to calculate the time constant ν'/τ of the reaction. Of course ν' is not a constant during the expansion since its value depends on the radius but this point will be ignored at first.

At a place where we have N neutrons/cm^3 there will be N/τ fissions/cm^3 sec and therefore if ε is the energy release in erg/fission the volume rate of energy generation is $(\varepsilon/\tau)N$. Hence the total energy released in unit volume between time $-\infty$ and time t is

$$W = (\varepsilon/\nu') N e^{\nu' t/\tau}$$

Most of this energy goes at once into kinetic energy of the fission fragments which are quickly brought to rest in the material by communication of their energy largely to thermal kinetic energy of motion to the other atoms of the active stuff.

The course of events is shown in Fig. 3. The units on the scale of abscissas are units of $\nu' t/\tau$. If there was no expansion, and if the rate of reaction toward the end was not slowed down by depletion of active material, then the energy released up to a given time in erg/cm^3 would be given by the values on the upper logarithmic scale. The places on this scale marked 100%, 10% and 1% respectively show the energy released in unit volume for these three values of the efficiency. A second logarithmic scale shows the growth of the neutron density with time under these assumptions.

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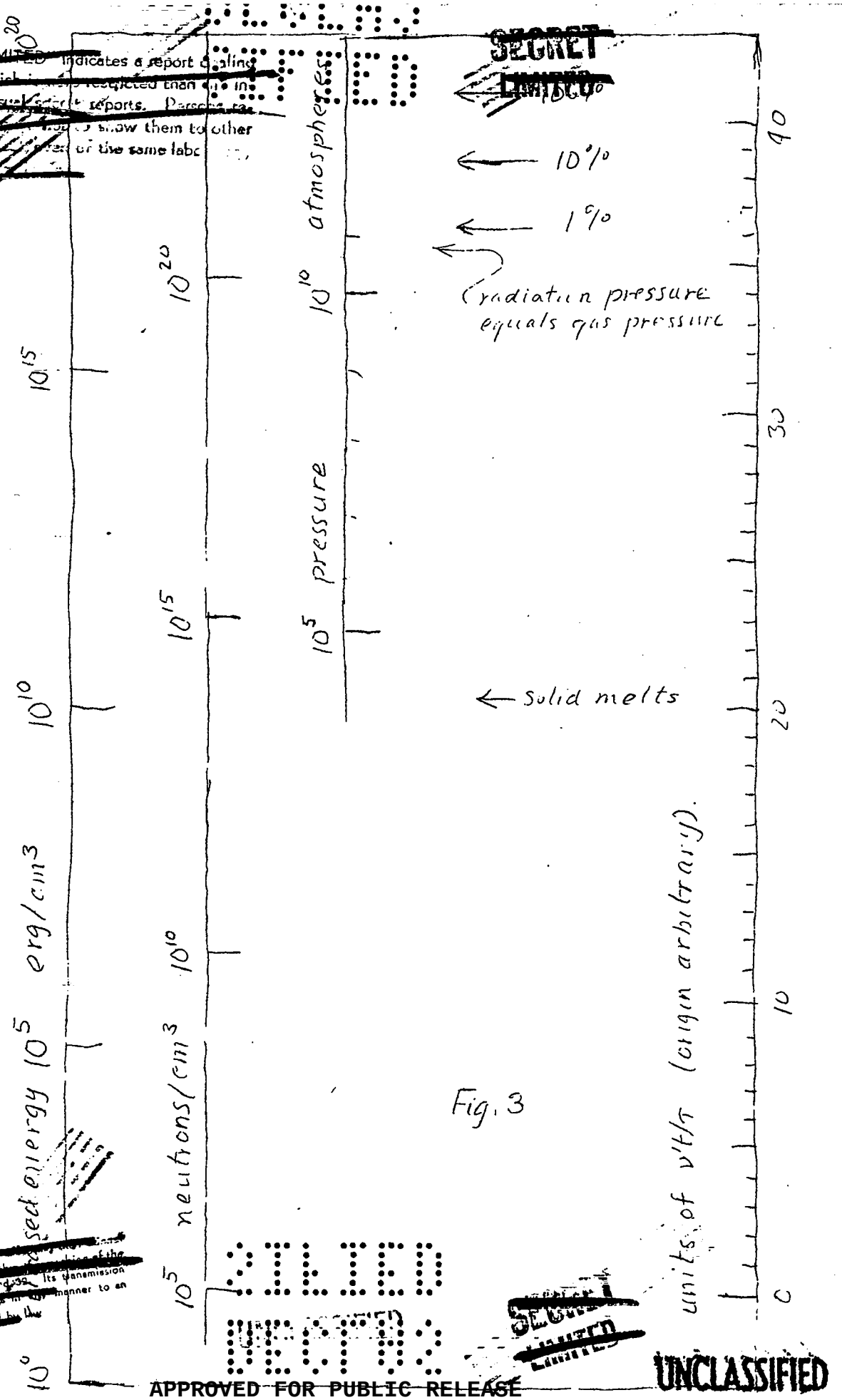


Fig. 3

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It can be calculated that the pressure in atmospheres is very roughly like the values given on the third scale. At a point just below 10^{17} erg/cm^3 evolved the radiation pressure is equal to the gas pressure, after that radiation pressure predominates. Near 10^{10} erg/cm^3 is the place where the solid melts so up to this time nothing very drastic has happened - the important phenomena occur in the next 20 units of $\nu' t/\tau$.

Very roughly we may estimate, as follows for masses not much larger than the critical mass, the combination of factors on which the efficiency depends: In a time of the order τ/ν' the material moves from R_0 to R so acquires a velocity

$$v \sim (\nu'/\tau)(R - R_0)$$

Writing $R_0 = R_{c0}(1+\Delta)$ we find that

$$R - R_0 = \tfrac{1}{2}\Delta R_{c0}$$

The kinetic energy per gram that is acquired by the material is

$$v^2/2 \sim \tfrac{1}{4}(\nu'/\tau)^2 \Delta^2 R_{cc}^2$$

The total energy released is greater in the order $pV \div pdV$ or $2/3\Delta$. Let $\mathcal{E} = 7.10^{17}$ erg/gram be the energy release for complete conversion then the efficiency is of the order

$$f \approx (\nu'^2/\mathcal{E}\tau^2)(\Delta^2/4) R_{c0}^2 (2/3\Delta)$$

or

$$f \approx (1/6)(\nu'^2/\mathcal{E}\tau^2) R_{c0}^2 \Delta$$

For an untampered gadget

$$\nu' \approx 2(\nu-1)\Delta$$

giving

$$\boxed{f = \frac{2}{3}\frac{(\nu-1)^2 R_{c0}^2}{\mathcal{E}\tau^2}\Delta^3}$$

Putting in the known constants

$$\mathcal{E} = 7.10^{17} \qquad \tau = 10^{-8} \qquad R_c = 9$$

we find

$$f = K\Delta^3 \quad \text{with} \quad K = 1.1$$

If this very rough calculation is replaced by a more accurate one the only change is to alter the value of the coefficient K. The calculations are not yet complete, but the true value is probably $K \approx \frac{1}{4}$ to $\frac{1}{2}$.

Hence for a mass that is twice the critical mass, $R_0 = \sqrt[3]{2}\, R_c$ so $\Delta = 0.25$ and the efficiency comes out less than 1%. We see that the efficiency is extremely low even when this much valuable material is used.

Notice that τ varies inversely as the velocity of the neutrons. Hence it is advantageous for the neutrons to be fast. The efficiency depends on the nuclear properties through the factors

$$f \sim \frac{v^2(\nu-1)}{\mathcal{E}}\frac{\sigma_f}{\sigma_t}\Delta^3$$

where v is the mean speed of the neutrons and the other symbols are already defined.

In the above treatment we have considered only the effect of the general expansion of the bomb material. There is an additional effect which tends to stop the reaction: as the pressure builds up it begins to blow off material at the outer edge of the bomb. This turns out to be of comparable importance in

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stopping the reaction to the general expansion of the interior. However the formula for the efficiency can be shown to be unchanged in form; the edge expansion manifests itself simply in a reduction in the constant K. The effect of blowing off the edge has been already taken into account in the more accurate estimate of K given above.

14. Effect of Tamper on Efficiency

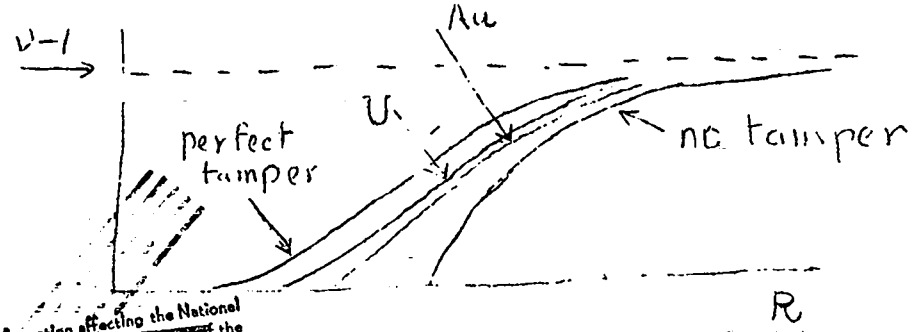
For a given mass of active material, tamper always increases efficiency. It acts both to reflect neutrons back into the active material and by its inertia to slow the expansion thus giving opportunity for the reaction to proceed farther before it is stopped by the expansion.

However the increase in efficiency given by a good tamper is not as large as one might judge simply from the reduction in the critical mass produced by the tamper. This is due to the fact that the neutrons which are returned by diffusion into and back out of the tamper take a long time to return, particularly since they are slowed down by inelastic impacts in the tamper material.

The time scale, for masses near critical where one has to rely on the slowest neutrons to keep the chain going, now becomes effectively the lifetime of neutrons in the tamper, rather than the lifetime in the bomb. The lifetime of neutrons in a U tamper is $\sim 10^{-7}$ sec, ten times that in the bomb. The efficiency is consequently very small just above the critical mass, so to some extent the reduction in critical mass is of no use to us.

One can get a picture of the effect of tamper on efficiency from Fig. 4, in which U ν' is plotted against bomb radius for various tamper materials. The time scale is given by τ/ν' ; the efficiency, as we have seen in the preceeding section, is inversely proportional to the square of the time scale. Thus $f \sim \nu'^2$.

Fig. 4.



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If we use good tamper (U) the efficiency is very low near the critical mass due to the small slope of the ν' vs.R curve near $\nu' = 0$. When one uses a mass sufficiently greater than the critical to get good efficiency there is not very much difference between U and Au as tamper materials.

It turns out that if one is using 4 M_c and the U tamper, then only about 15% more active material is needed to get the same energy release with a gold tamper, although the critical masses differ by 50%.

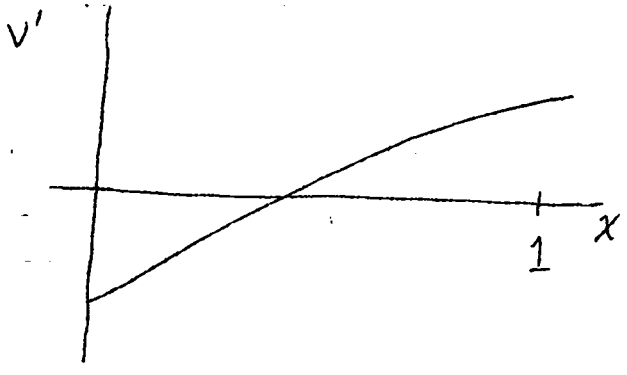
In addition to reflecting neutrons, the tamper also inhibits the tendency of the edge of the bomb to blow off. The edge expands into the tamper material, starting a shock wave which compresses the tamper material sixteenfold. These edge effects as remarked in Sec. 13 always act to reduce the factor K in the formula, $f = K\Delta^3$, but not by as great an amount in the case of tamped bomb as in the case of the untamped bomb.

15. Detonation

Before firing, the active material must be disposed in such a way that the effective neutron number ν' is less than unity. The act of firing consists in producing a rearrangement such that after the rearrangement ν' is greater than unity.

This problem is complicated by the fact that, as we have seen, we need to deal with a total mass of active material considerably greater than the critical in order to get appreciable efficiency.

For any proposed type of rearrangement we may introduce a coordinate χ which changes from 0 to 1 as the rearrangement of parts proceeds from its initial to its final value.



Schematically ν' will vary with χ along some such curve as is indicated in the sketch. Since the rearrangement proceeds at a finite speed there will be a finite time interval during which ν' though positive is much smaller than its final value. As considered in more detail later there will always be some un-

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avoidable sources of neutrons in the active material. In any scheme of rearrangement some fairly massive amount of material will have to be moved a distance of the order of $R_c \sim 10$ cm. Assuming a speed of 3000 ft/sec can be imparted with some type of gun this means that the time it takes to put the pieces of the bomb together is $\sim 10^{-4}$ sec. Since the whole explosion is over in a time $\sim 75\,\tau/\nu' = \frac{10^{-6}}{\nu'}$ sec, we see that, except for very small ν' ($\nu' < .01$), an explosion started by a premature neutron will be all finished before there is time for the pieces to move an appreciable distance. Thus if neutron multiplication happens to start before the pieces reach their final configuration an explosion will occur that is of lower efficiency corresponding to the lower value of ν' at the instant of explosion.

To avoid predetonation it is therefore necessary to keep the neutron background as low as possible and to effect the rearrangement as rapidly as possible.

16. Probability of Predetonation

Since it will be clearly impossible to reduce the neutron background rigorously to zero, there will always be some chance of predetonation. In this section we try to see how great this chance is in order to see how this affects the firing problem.

The chance of predetonation is dependent on the likelihood of a neutron appearing in the active mass while ν' is still small and on the likelihood that such a neutron will really set off a chain reaction. With just a single neutron released when $\nu' > 0$ it is by no means certain that a chain reaction will start, since any particular neutron may escape from the active material without causing a chain reaction.

The question can be considered in relation to a little gambling problem. In tossing loaded coins suppose p is the probability of winning and q that of losing. Let P_n be the probability of losing all of an initial stock of n coins. On the first toss either one wins and thus has $(n+1)$ coins or loses and thus has $(n-1)$ coins. Hence the probability P_n is given by

$$P_n = p\,P_{n+1} + q\,P_{n-1}$$

the solution of which is

$$P_n = (q/p)^n$$

Identifying this with the neutron multiplication problem one can show that $q/p = 1 - \nu'$. Hence the probability of not starting a chain reaction with one neutron is $(1 - \nu')$ or ν' is the probability that any one neutron will start a chain reaction.

Suppose now that there is a source of N neutron/sec. Let $P(t)$ be the probability of not getting a predetonation up to the instant t. In the interval dt we have

$$dP = -N dt\, \nu' P$$

On the left the first three factors together give the probability of going off in a time dt, and the factor P is the probability of not having had a predetonation up to that time.

Near the value $\nu' = 0$ we may suppose that ν' varies linearly with time, $\nu' = \alpha t$. Hence, integrating the differential equation,

$$P = e^{-\frac{1}{2} N t^2} = e^{-\frac{1}{2} \frac{N}{\alpha} \nu'^2}$$

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where $N = Nt$ is the number of neutrons expected in the interval between $t = 0$, when $\nu' = 0$, and the time when the multiplication number has reached the value ν'. Evidently for a particular type of firing rearrangement N will vary inversely as the velocity with which the firing rearrangement is carried out.

For example consider a bomb whose mass is between two and three critical masses, for which the final value of ν' is 0.3 and suppose that $N = 10^4$ neutrons/sec from unavoidable sources. Also suppose that one piece must move $d = 10$ cm from the $\nu' = 0.0$ configuration to the final $\nu' = 0.3$ configuration. Suppose that this piece has a velocity of 10^5 cm/sec then $\bar{N} = 1$ and

$$P = e^{-0.15}$$

so there is approximately a 15% chance of predetonation.

This is the chance of predetonation any time up to that at which the final value of ν' is reached. In this example the exponent is small enough that the chance of predetonation, $(1 - P)$, is given by the linear approximation.

$$(1 - P) = \frac{1}{2} \bar{N} \nu'$$

Since the efficiency varies as ν'^3 one will get an explosion of less than $\frac{1}{4}$ of the maximum if it goes off before ν' has reached the value $0.3/\sqrt[3]{4} = 0.19$. Hence the probability of an explosion giving less than 25% of the maximum value is

$$(.19/.3)^2 \times .15 = 6\%$$

The example serves to indicate the importance of taking great pains to get the least possible neutron background, and of shooting the firing rearrangement with the maximum possible velocity. It seems one should strive for a neutron background of 10000 neutron/sec or less and firing velocities of 3000 ft/sec or more. Both of these are difficult of attainment.

17. Fizzles

The question now arises: what if by bad luck or because the neutron background is very high, the bomb goes off when ν' is very close to zero? It is important to know whether the enemy will have an opportunity to inspect the remains and recover the material. We shall see that this is not a worry; in any event the bomb will generate enough energy to completely destroy itself.

It has been remarked in the last section that for very small ν' ($\nu' < .01$), the explosion takes so long that the pieces do have time to move an appreciable distance before the reaction ends. Thus even if a neutron enters and starts a chain just when $\nu' = 0$ there will be time for ν' to rise to a positive value, and give an efficiency small, but greater than zero.

Suppose, then, that a neutron is released when $\nu' = 0$. The number of neutrons builds up according to the equation

$$N = e^{(\nu' - 1)N}$$

As a first approximation we may suppose ν' varies linearly as the pieces move from the point where $\nu' = 0$, so

$$\nu' = \nu'_0 \left(\frac{x}{d}\right)$$

where ν'_0 is the value of ν' when the pieces reach their final op-

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timal configuration, and d_0 is the distance to reach this configuration. If the velocity of fire is v, we have $x = vt$,

$$\ln N = \int_0^t (\nu'/\tau)\,dt = \frac{1}{2}\frac{\nu_0 v}{d_0 \tau} t^2$$

Suppose the reaction continues until about 10^{22} neutrons are produced, which would correspond to an energy production equivalent to 100 tons of TNT. Then, at the end of the reaction

$$\ln N = \ln 10^{22} \simeq 50.$$

(We can check this assumption after we have completed our estimate of the energy release. However, since the final number of neutrons enters only in the logarithm of a large number, our result is quite insensitive to what we take for N at this point.)

Thus the reaction ends when

$$\frac{1}{2}\frac{\nu_0 v}{d_0 \tau} t^2 = 50 \qquad x^2 = v^2 t^2 = 100 \frac{d_0 v \tau}{\nu_0} \qquad \nu' = \nu_0 \frac{x}{d_0}$$

$$= 10\sqrt{\nu_0 \frac{v\tau}{d_0}}$$

The efficiency is

$$f \sim \frac{1}{2}\nu'^3 = 500\,\nu_0^{3/2}\left(\frac{v\tau}{d_0}\right)^{3/2}$$

Using the same figures as in the precoeding section $(\nu_0 = .3,\ v = 10^5,\ d_0 = 10)$ we find $f = 8 \times 10^{-5}$

The mass of 25 in the bomb is about 40 kg. The mass used up is thus $40 \times 8 \times 10^{-3} = .003$ kg, and the energy release is .003 x 20000 = 60 tons of TNT equivalent, ample to destroy the bomb.

18. Detonating Source

To avoid predetonation we must make sure that there is only a small probability of a neutron appearing while the pieces of the bomb are being put together. On the other hand, when the pieces reach their best position we want to be very sure that a neutron starts the reaction before the pieces have a chance to seperate or break. It may be possible to make the projectile seat and stay in the desired position. Failing in this, or in any event as extra insurance, another possibility is to provide a strong neutron source which becomes active as soon as the pieces come into position. For example one might use a Ra + Be source in which the Ra is on one piece and the Be on the other so neutrons are only produced when the pieces are close to the proper relative position.

We can easily estimate the strength of source required. After the source starts working, we want a high probability of detonation before the pieces have time to move more than say 1 cm. This means that N, the neutrons/sec from the source must be large enough that

$$\frac{1}{2}\frac{N d \nu'}{v} \gg 1 \quad (\text{say} = 10)$$

$$N = 10^7 \text{ neutrons/sec.}$$

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This is the yield from 1 gr Ra intimately mixed with beryllium. Hence it might be necessary to ~~rise~~ several grams of radium since it will probably not be used efficiently in this type of source.

Some other substance such as polonium that is not so γ-active as radium will probably prove more satisfactory.

Evidently a source of this strength that can be activated within about 10^{-5} sec and is mechanically rugged enough to stand the shocks associated with firing presents a difficult problem.

19. Neutron Background

There are three recognized sources of neutrons which provide the background which gives rise to danger of predetonation: (a) cosmic ray neutrons, (b) spontaneous fission, (c) nuclear reactions which produce neutrons.

(a) Cosmic Rays. The number of cosmic ray neutrons is about 1 per cm^2 per minute which is too few to be of any importance.

(b) Spontaneous fission. The spontaneous fission rate is known only for 28 which is responsible for the fission activity of ordinary U. At present we have only upper limits for 25 and 49 since the activity of these has not been detected. The known facts are

28 gives 15 neutrons/kg sec.
25 " < 150 "
49 " < 500 "

It is considered probable that the rates for 25 and 49 are much smaller than these upper limits. Even if 25 and 49 were the same as 28, a 40 kg bomb would have a background from this source of 600 neutron/sec. This does not seem difficult to beat.

But if U is used as tamper this will weigh about a ton which gives 15000 neutron/sec. Of course not all of these will get into the active material but one may expect a background of several thousand per second from this source.

Thus with a U tamper one is faced with the problem of high velocity firing. In the range of moderately high efficiencies, say 4 M_c of active material, it might for this reason not be worth while to use a U tamper, since as we have seen, an inactive tamper will cost only about 15% more active material. Or one might use a compromise in which the tamper was an inner layer of U, backed up by inactive material; for masses this large the time scale is so short that neutrons do not have time to penetrate more than about 5 cm into the tamper anyway.

(c) Nuclear reactions. The only important reactions are the (α, n) reactions of light elements which might be present as impurities. The (γ, n) reactions have a negligible yield.

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Let us examine what sort of limit on light element impurities in the active material is set by the need of holding down the neutron background from this source.

The problem is particularly bad for 49 since its half-life is only 20000 years. Its mean life is thus 30000 years $= 10^{12}$ sec. Thus 10 kg of 49, containing 2.5×10^{25} nuclei gives 2.5×10^{13} α-particles/sec.

The yield from Ra α's on Be is 1.2×10^{-4} and the shorter range from α's of 49 as compared with those of Ra and its equilibrium products will perhaps cut this figure in half, say $6 \cdot 10^{-5}$. Since the stopping power for α's of these energies is proportional to $\sqrt{A}$ where A is the atomic weight, the stopping power per gram is proportional to $1/\sqrt{A}$.

If the concentration by weight of Be in the active material is C then the yield of neutron/sec is

$$\sqrt{239/9} \cdot c \cdot N_\alpha \cdot y$$

where N_α is the number of α's per second and y is the yield. Hence to get 10000 neutrons/sec one would need to have a concentration given by

$$\sqrt{239/9} \cdot c \cdot 2.5 \cdot 10^{13} \cdot 6 \times 10^{-5} = 10^4$$

that is $c \sim 10^{-6}$ which is, of course, a very low concentration of anything in anything else.

The yield drops rapidly as one goes to elements of higher atomic weight because of the increased Coulomb barrier. So it is unnecessary to consider limits on elements beyond Ca as long as ordinary standards of purity are maintained.

Experiments on the yields with light elements need to be done. One can base some rough guesses on the standard barrier penetration formulas and find the following upper limits on the concentration by weight for several light elements for production of 10^4 neutron/sec/

Li	2×10^{-5}	
Be	~~10^{-7}~~ 10^{-6}	
B	$2 \cdot 10^{-6}$	
C	$2 \cdot 10^{-4}$	*
N	-	**
O	2×10^{-3}	***
F	2×10^{-5}	

* Low yield because only C^{13} contributes.
** $(\alpha\text{-}n)$ reaction not energetically possible.
*** Low yield because only O^{17} contributes.
The effect of several impurities simultaneously present is of course additive.

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It is thus recognized that the preparation and handling of the 49 in such a way as to attain and maintain such high standards of purity is an extremely difficult problem. And it seems very probable that the neutron background will be high and therefore high velocity firing will be desirable.

With 25 the situation is much more favorable. The α's come from 24 present in normal U to about 1/10000. If all 24 goes with 25 in the separation from 28 we shall have 1/100 of 24 in the 25. The lifetime of 24 is 100 times that of 49 so the

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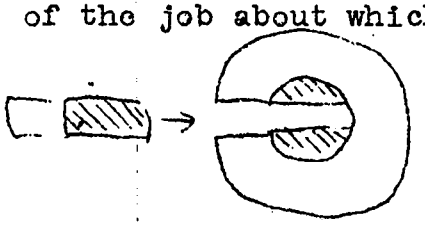
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concentration of impurities in 25 may be 10^4 times that in 49 for the same background, which is not at all difficult of attainment.

To summarize: 49 will be extremely difficult to work with from the stand-point of neutron background whereas 25 without U tamper will be not very difficult.

20. Shooting

We now consider briefly the problem of the actual mechanics of shooting so that the pieces are brought together with a relative velocity of the order of 10^5 cm/sec or more. This is the part of the job about which we know least at present.



One way is to use a sphere and to shoot into it a cylindrical plug made of some active material and some tamper, as in the sketch. This avoids fancy shapes and gives the most favorable shape, for shooting; to the projected piece whose mass would be of the order of 100 lbs.

The highest muzzle velocity available in U. S. Army guns is one whose bore is 4.7 inches and whose barrel is 21 feet long. This gives a 50 lb. projectile a muzzle velocity of 3150 ft/sec. The gun weighs 5 tons. It appears that the ratio of projectile mass to gun mass is about constant for different guns so a 100 lb. projectile would require a gun weighing about 10 tons.

The weight of the gun varies very roughly as the cube of the muzzle velocity hence there is a high premium on using lower velocities of fire.

Another possibility is to use two guns and to fire two projectiles at each other. For the same relative velocity this arrangement requires about 1/8 as much total gun weight. Here the worst difficulty lies in timing the two guns. This can be partly overcome by using an elongated tamper mass and putting all the active material in the projectiles so it does not matter exactly where they meet. We have been told that at present it would be possible to synchronize so the spread in places of impact on various shots would be 2 or 3 feet. One serious restriction imposed by these shooting methods is that the mass of active material that can be gotten together is limited by the fact that each piece separately must be non-explosive. Since the separate pieces are not of the best shape, nor surrounded by the best tamper material, one is not limited to two critical masses for the completed bomb, but might perhaps get as high as four critical masses. However in the two gun scheme, if the final mass is to be $\sim$ 4Mc, each piece separately would probably be explosive as soon as it entered the tamper, and better synchronization would be required. It seems worthwhile to investigate whether present performance might not be improved by a factor ten.

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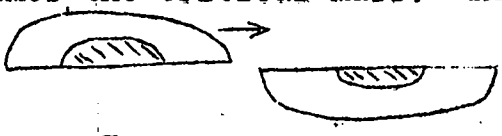
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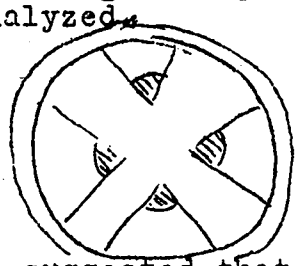
Severe restrictions on the mass of the bomb can be circumvented by using pieces of shape more difficult to shoot. For example a flat plate of actual material tamped on only one side, has a mimimum thickness below which it can no longer support a chain reaction, no matter how large its area, because of neutron leakage across the untamped surface. If two such plates were slid together, untamped surfaces in contact, the resulting arrangement could be well over the critical thickness for a plate tamped on both sides, and the mass would depend only on the area of the plates.

Calculations show that the critical mass of a well tamped spheroid, whose major axis is five times its minor axis, is only 35% larger than the critical mass of a sphere. If such a spheroid 10 cm thick and 50 cm in diameter were sliced in half, each piece would be sub-critical though the total mass, 250 Kg, is 12 times the critical mass. The efficiency of such an arrangement would be quite good, since the expansion tends to bring the material more and more nearly into a spherical shape.



Thus there are many ordnance questions we would like to have answered. We would like to know how well guns can be synchronized. We shall need information about the possibilities of firing other than cylindrical shapes at lower velocities. Also we shall need to know the mechanical effects of the blast wave preceeding the projectile in the gun barrel. Also whether the projectile can be made to seat itself properly and whether a piston of inactive material may be used to drive the active material into place, this being desirable because thus the active material might be kept out of the gun barrel which to some extent acts as a tamper.

Various other shooting arrangements have been suggested but as yet not carefully analyzed.



For example it has been suggested that the pieces might be mounted on a ring as in the sketch. If explosive material were distributed around the ring and fired the pieces would be blown inward to form a sphere.

Another more likely possibility is to have the sphere assembled but with a wedge of neutron-absorbing material built into it, which on firing would be blown out by an explosive charge causing k to go from less than unity to more than unity. Here the difficulty lies in the fact that no material is known whose absorption coefficient for fast neutrons is much larger than the emission coefficient of the bomb material. Hence the absorbing plug will need to have a volume comparable to that of the absorber and when removed will leave the active material in an unfavorable configuration, equivalent to a low mean density.

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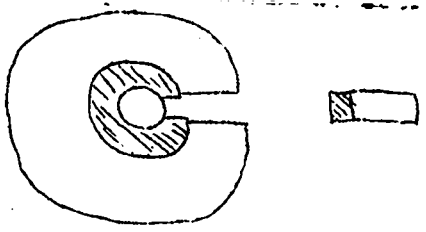
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21. Autocatalytic Methods

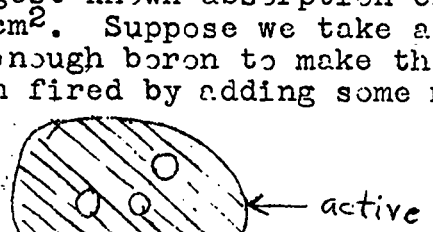
The term "autocatalytic method" is being used to describe any arrangement in which the motions of material produced by the reaction will act, at least for a time, to increase ν' rather than to decrease it. Evidently if arrangements having this property can be developed they would be very valuable, especially if the tendency toward increasing ν' was possessed to any marked degree.

Suppose we had an arrangement in which for example ν' would increase of its own accord from a low value like 0.01 up to a value 10 to 50 times greater. The firing problem would be simplified by the low initial value of ν', and the efficiency would be maintained by the tendency to develop a high value of ν' as the reaction proceeds. It may be that a method of this kind will be absolutely essential for utilization of 49 owing to the difficulties of high neutron background from (α, n) reactions with the impurities as already discussed.



The simplest scheme which might be autocatalytic is indicated in the sketch where the active material is disposed in a hollow shell. Suppose that when the firing plug is in place one has just the critical mass for this configuration. If as the reaction proceeds the expansion were to proceed only inward it is easy to see from diffusion theory that ν' would increase. Of course in actual fact it will proceed outward (tending to decrease ν') as well as inward and the outward expansion would in reality give the dominant effect. However, even if the outward expansion were very small compared to the inward expansion it has been calculated that this method gives very low efficiency: with 12 Mc an efficiency of only about 10^{-9} was calculated.

A better arrangement is the "boron bubble" scheme. B^{10} has the largest known absorption cross-section for fast neutrons, $1.52 \cdot 10^{-24}$ cm^2. Suppose we take a large mass of active material and put in enough boron to make the mass just critical. The device is then fired by adding some more active material or tamper.



As the reaction proceeds the boron is compressed and is less effective at absorbing neutrons than when not compressed. This can be seen most readily if one considers the case in which the bubbles are large compared to the mean depth in which a neutron goes in boron before being absorbed. Then their effectiveness in removing neutrons will be proportional to their total area and so will drop on compression. Hence ν' will increase as the bubbles are compressed. If the bomb is sufficiently large this tendency is bound to overweigh the opposing one due to the general expansion of the bomb material, since the distance the edge of the bomb must move to produce a given decrease in ν' increases with the radius of the bomb, whereas for a larger bomb the distance the edge of a

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bubble must move is unchanged, since it is not necessary to increase the radius of the bubbles but only to use more of them.

The density of particles (electrons plus nuclei) in boron is 8.3 x 10^{23} particle/cm^3 while in uranium it is more than 5 times greater. Therefore as soon as the reaction has proceeded to the point where there is a high degree of ionization and the material behaves as a gas there will be a great action to compress the boron. An opposing tendency to the one desired will be the stirring or turbulence acting to mix the boron uniformly with the uniform, but the time scale is too short for this to be effective.

It can be shown that if initially $\nu' = 0$, allowing for the boron absorption, and if no expansion of the outer edge occurs then ν' will rise to $\nu' \sim \frac{1}{4}(\nu - 1)$ by compression of the boron. This scheme requires at least five times the critical mass for no boron, and the efficiency is low unless considerably more is used.

If one uses just that amount of boron which makes twice the no-boron critical mass be just critical, then the efficiency is lower by a factor at least 30.

All autocatalytic schemes that have been thought of so far require large amounts of active material, are low in efficiency unless very large amounts are used, and are dangerous to handle. Some bright ideas are needed.

22. Conclusion

From the preceeding outline we see that the immediate experimental program is largely concerned with measuring the neutron properties of various materials, and with the ordnance problem. It is also necessary to start now studies on techniques for direct experimental determination of critical size and time scale, working with large but sub-critical amounts of active material.

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MANHATTAN DISTRICT HISTORY

BOOK I - GENERAL

VOLUME 1 - GENERAL

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h. Book VIII, Los Alamos Project (Y), deals with all the activities which were carried on at the Los Alamos Laboratories, Los Alamos, New Mexico, including principally: research, design, final processing, construction, assembly and testing of the bombs themselves; site selection and land acquisition; construction, administration and operation of the community, with its housing, utilities, commercial facilities and services; and construction, administration and operation of the so-called technical area and of various outlying, "satellite", sites. This book also tells of numerous other activities which were carried on at other places scattered through the United States, all of which may be regarded as auxiliary to the critical major work at Los Alamos, some of them of very great importance. The technical work at Los Alamos was carried on under contract with the University of California, directed by Dr. J. R. Oppenheimer of that University; the general administration of the community, which was operated as a military post, and all construction work were under the local direction of an Army officer - the Commanding Officer. Major construction work was performed principally, in the earlier days, by M. M. Sundt Construction Company, and then, through successive large expansions, by Robert E. McKee. The Architect-Engineer for most of the design work was W. C. Kruger.

The non-scientific part of the history of the Los Alamos Project is in Volume 1 of Book VIII; the technical part of its history is in Volume 2; and the auxiliary activities are described, in various chapters, in Volume 3.

Of the auxiliary activities, particular mention should be made of: the Los Angeles Procurement Office, which handled most of the

diverse procurement required for all the Los Alamos activities; and the Camel Project, which covered some complex research, testing and production work and served as an emergency reserve in case of catastrophe at Los Alamos. Other important auxiliary subjects described in Volume 3 include: Activities of Ohio State Cryogenic Laboratory; Dayton Project; Navy Participation; Sandia; Boron; Operation Crossroads (in which personnel of the Manhattan District took an important part); and various other miscellaneous activities.

The real climax of the Los Alamos Project - indeed, the real climax of the whole of the Manhattan Project - is described in the "Technical" volume of this book. This was the so-called Trinity Test, the first man-made atomic bomb explosion of all time, which took place in the desert at Alamogordo Air Base, New Mexico, on 16 July 1945. Not until that test was successfully made could anyone connected with the enterprise be sure that the project would produce any concrete results.

The official climax of the Manhattan Project - the official culmination of the years of effort of thousands of people and of the expenditure of about two billions of dollars - was the combat bombing of Japan, at Hiroshima and Nagasaki, in August 1945. This also is described in the "Technical" Volume (Vol. 2) of Book VIII, in a chapter headed: "Project Alberta".

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SECTION 2 - THE MISSION OF THE MANHATTAN DISTRICT

2-1. The District's Mission, in Simplest Terms - Reduced to its simplest terms, the mission of the Manhattan District was to develop and manufacture atomic bombs for combat use, at the earliest possible date, and ahead of the enemy, in order to help the United States and its Allies to bring World War II to a successful conclusion with the least delay and the greatest possible conservation of life.

2-2. Justification - The world's history during the first few weeks following the dropping of the first combat bomb on Hiroshima on 6 August 1945 proved conclusively not only that this mission of the Manhattan District was successfully accomplished but also that this mission - with its accompanying expenditure of about two billions of dollars - was completely justified.

a. One phase of this justification has been described impressively by Major General L. R. Groves, in a public address given in June 1946, in the following words:

"....While the mission was to develop the atomic bomb, the real objective was to save the lives of thousands of America's best men - by shortening the war.

"The war was not won by the atomic bomb. It was won by our fighting men, backed up by the best of weapons provided for them by the industrial might of the nation. The Japanese had lost the war long before the Hiroshima bombing, but the people did not know it, and their leaders did not admit it. Both people and leaders knew it and admitted it within a few hours after they learned of Hiroshima.

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"I believe the historians of the future will be unanimous in the conclusion that the atomic bomb ended the war in a more abrupt and sudden manner than any war has been ended since the day of that other great surprise weapon, the Trojan Horse.

"Let us look for a moment at the timetable of last summer. On the 16th of July, the first atomic bomb test occurred in New Mexico. News of the successful results were rushed to President Truman, then in Potsdam, and in a few days, - on the 26th, to be exact - the Potsdam surrender ultimatum was sent to Japan, warning her that unless she surrendered she would be destroyed.

"On the 29th, Radio Tokyo broadcast that the Japanese Premier scorned the Allied warning as 'unworthy of public notice.' Eight days later, Hiroshima was hit by the first atomic bomb. We told the government and the people of Japan what had hit them. That was August 6, 1945. Two days later, Russia hurriedly entered the war against Japan. The next day, the second atomic bomb fell on Nagasaki. On the tenth of August, the Swiss Charge d'Affaires in Washington sent a note to our Secretary of State, stating that the Japanese government was ready to accept the terms of the Potsdam Ultimatum. On the 14th, after almost four years of unremitting war and eight days after the first atomic bomb was dropped, the Japanese government unconditionally surrendered.

"The men scheduled to enter Japan the hard way - across the beaches - and their mothers and fathers, wives and children, soon realized that they had had an infinite stake in the two billion dollar program which had been such a closely guarded secret for more than three years . . ."

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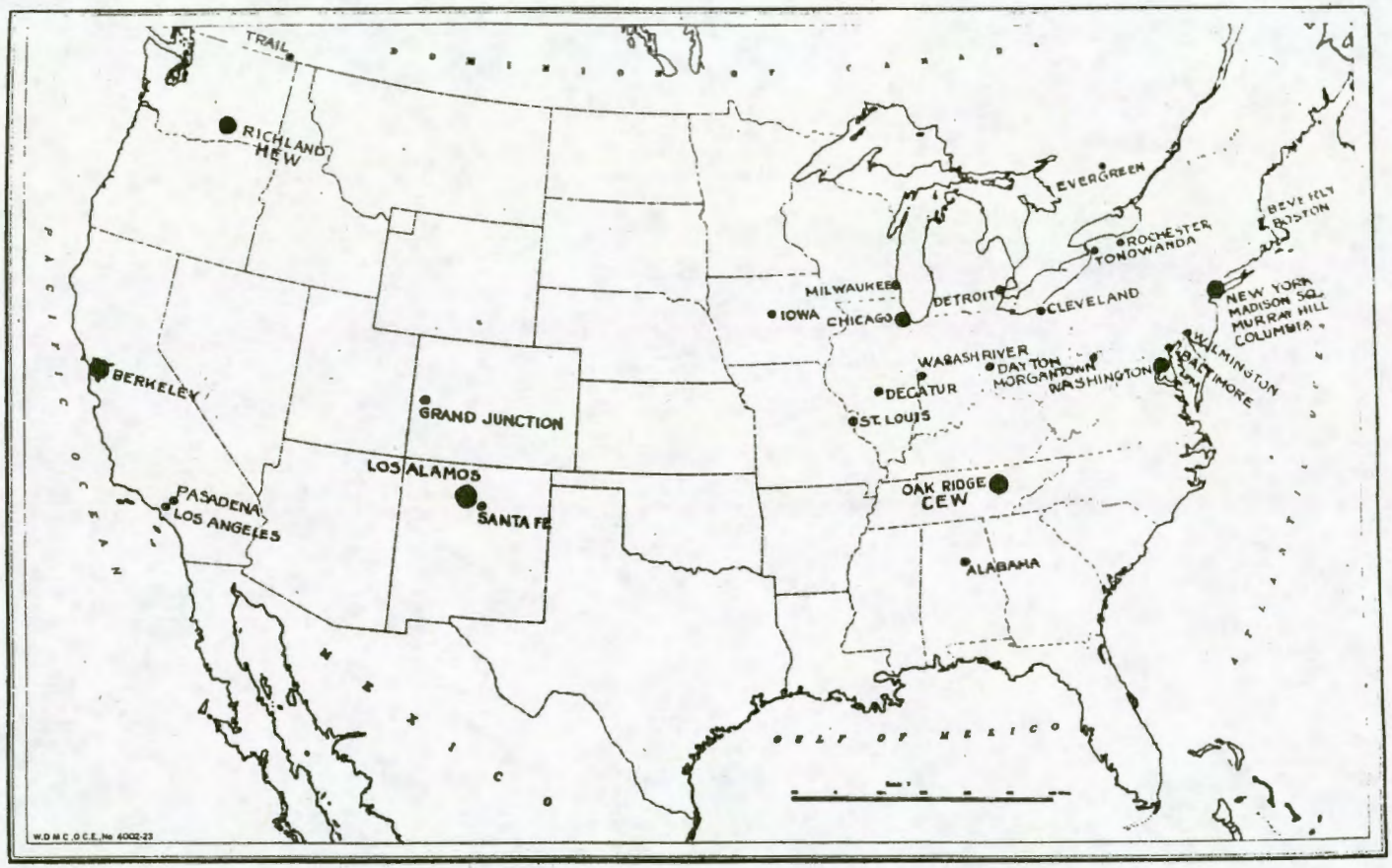
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TO
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TO

MANHATTAN DISTRICT HISTORY

BOOK VIII, LOS ALAMOS PROJECT (Y)

VOLUME 2, TECHNICAL

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PREFACE

The technical history for Project Y, from its inception until August 1945, has been recorded in Book VIII, Volume 2. It is the purpose of this work to present the activities of the Los Alamos Laboratory from August 1945 until the end of December 1946, when the Manhattan District relinquished its control. No attempt has been made to interpret events, or to forecast the importance of scientific developments during this period. This book is merely a chronicle of the reorganization, philosophy and subsequent achievements which transpired in this critical interim period following the cessation of hostilities.

It will be noted that this supplement is treated as an individual book and that for the sake of consistency, it follows the mechanical arrangement used in the basic volume. This system deviates somewhat from the established standard for the Manhattan District histories, in its method of paragraphing, duplication, indexing and size. Approval for this deviation was granted for both the basic work and its supplement.

The method of cross reference employed in this book requires some explanation. Whenever an allusion is made to material within the supplemental volume, only the paragraph number is used as a parenthetical reference, e.g., (par. 1.23). However, to avoid confusion when reference is made to another volume of the Los Alamos History, a full description follows, e.g., (Book VIII, Vol. 1, par. 4.34).

Historical material for this supplement came from the Director, Dr. N. E. Bradbury, the Administrative Associate Director, Lt. Col. A. W. Betts, the seven Technical Division Leaders: Carson Mark, J. M. B. Kellogg, Marshall Holloway, Eric Jette, Max Roy, R. W. Henderson, and Ralph Carlisle Smith. Further assistance was rendered by J. F. Mullaney, Report Editor, and A. E. Dyhre,

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Atomic Energy Act 1946
Specific Restricted Data
Clearance Required

Business Manager. The various division Progress Reports were consulted frequently to maintain the chronological order of events, and the central files were extensively used for documentary material.

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1.37 The basic design of a "composite" implosion weapon using both plutonium and uranium 235 was developed for use under implosion conditions similar to those previously employed for pure plutonium. (par. 3.17)

Crossroads Operation

1.38 In December 1945, the laboratory was informed that a test of atomic weapons against naval vessels was proposed, and the laboratory was requested to undertake the technical direction of this test as well as to supply the atomic weapons to be used therein. Preliminary meetings were held in December 1945 and January 1946, during the course of which it was decided to:

1. Set up a Joint Task Force Operation with the Army, Navy, and Manhattan Engineer District.

2. To employ the same type of atomic weapon as used at Nagasaki.

3. To recommend three types of test to be conducted in the order given below:

Able: Air burst over an array of representative ships.

Baker: Shallow water burst under an array of representative ships.

Charlie: Deep water burst under an array of representative ships.

1.39 The atoll of Bikini in the Marshall Islands was selected by the Navy as a satisfactory location for tests "Able" and "Baker" with possibility that test "Charlie" might be conducted on the deep water side of the atoll.

1.40 The laboratory selected Dr. Ralph A. Sawyer as Technical Director for this operation, with Dr. Marshall Holloway (B-Division) and Mr. Roger Warner (Z-Division) under him as heads of the Los Alamos experimental groups and weapon preparation groups respectively.

3. The McNierney Cattle Case

2.104 On August 25, 1946, $1,350 was paid by the University to Mr. W. L. McNierney as compensation for loss suffered by him in connection with the sale of 140 head of cattle at reduced market value during September 1945 as the result of discoloration of cattle hair alleged to have been caused by exposure during the test at Alamogordo, New Mexico, on July 16, 1945.

4. Telephone and Telegraph

2.105 For reasons of security, payment of telephone and telegraph services was handled through the Business Office. All bills from Western Union, Railway Express (which handled much of the telegraphic service in order to assist us in maintaining security) and from the telephone company were billed to the Business Office, that office in turn collecting the amounts due from the various employees. This practice was discontinued as of the last of May 1946 after the relaxing of security regulations, inasmuch as it was then deemed safe to establish such accounts in individual names of employees at the Project.

5. Nursery School

2.106 Financing of the nursery school was handled by the University through the Business Office. It was the duty of that office to collect from the parents of the children enrolled, the tuition and the fees for lunches served. The Business Office in turn paid the school teachers, the food bills, maid service, dietician and other bills. Such services as nurse, janitor, utilities, buildings and laundry were not chargeable to the budget but were subsidized by the Government. The school continued as a responsibility of the Business Office until December 1, 1946, at which time it was directed by Colonel A. C. Nauman, in his letters of October 30, 1946, and November 25, 1946, that responsibility for operation of the nursery school (a part of Community Services) would be assumed by the Zia Company effective December 1, 1946.

6. Newspaper

2.107 As of June 21, 1946, the local newspaper, the Los Alamos Times,

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Chapter III

THEORETICAL PHYSICS DIVISION

Introduction

3.1 During the third period, August 1945 through the year 1946, the Theoretical Division continued its war-time program with certain modifications and on a reduced scale, and added to its interests the theoretical-physics research on thermonuclear systems formerly carried on in F Division (Book VIII, Vol. 2, par. 13.3). In the fall of 1945, much attention was given to the complex hydrodynamical problems involved in the interpretation of the blast measurements made at Trinity and at Hiroshima and Nagasaki; also, during this time, much effort was spent on the radiation hydrodynamics of the implosion fission bomb, largely because of the unexpectedly high efficiency of this weapon.

Organization

3.2 The difficulties of the early interim period affected Theoretical Division seriously. Of the Division Leader and the eight group leaders serving in August 1945, all had left by September 1946; early in this period most of the junior members of the division returned to the universities to resume their interrupted studies. The group structure of the division in August 1945, together with the date of termination of regular employment of the group leader, was as follows:

Group		Group Leader	Termination of Regular Employment
T-1	Implosion Dynamics	R. E. Peierls	January 1946
T-2	Diffusion Theory	R. Serber	November 1945
T-3	Efficiency Theory	V. F. Weisskopf	February 1946
T-4	Diffusion Problems	R. P. Feynman	October 1945
T-5	Computation	D. A. Flanders	September 1946
T-6	IBM Computations	E. Nelson	January 1946
T-7	Damage	J. O. Hirschfelder	August 1946
T-8	Composite Weapon	G. Placzek	May 1946

Many of the above-named group leaders were retained in consultant status.

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3.3 On 14 November 1945, Group F-1, which had been part of Theoretical Division up to June 1944 (Book VIII, Vol. 2, par. 13.3), returned to Theoretical Division and became Group T-7. As before, its concern was the theory of thermonuclear systems.

3.4 On 1 December 1945, Hans A. Bethe resigned as Theoretical Division Leader and shortly thereafter returned to his position at Cornell University. His successor was George Placzek, who had joined the Theoretical Division in May 1945 after working for several years with the Montreal group.

3.5 Early in 1946, a general reorganization took place, and the resulting group structure on 8 January 1946 was as follows:

Group		Group Leader	Termination of Regular Employment of Group Leader
T-1	Hydrodynamics	Joseph M. Keller	27 June 1946
T-2	(Group dissolved; personnel transferred to T-8)		
T-3	Efficiency Theory	V. F. Weisskopf	28 February 1946
T-4	Diffusion Problems	R. Ehrlich	9 January 1946
T-5	Computations	D. A. Flanders	4 September 1946
T-6	IBM Computations	R. W. Hamming	24 June 1946
T-7	Super	E. Teller	21 January 1946
T-8	Diffusion Theory	C. Mark	Did Not Terminate

3.6 The return of key personnel to the universities for the spring semester in 1946 necessitated considerable change. Groups T-2, T-3, and T-4 were dissolved and the personnel were transferred to the remaining groups.

3.7 Work on radiation hydrodynamics formerly carried on by Group T-3 became the concern of R. Landshoff, a member of Group T-7, who in May 1946 visited Ithaca, Rochester and Boston to discuss this work with former members of Group T-3. Group T-1 was dissolved in June; some of the problems worked on by this group were distributed among the remaining groups. A new group, T-1, was formed under the leadership of F. Reines to consider the theory of the dragon (par. 3.38) and to

work on blast wave and damage problems which might arise. All computations, both manual and machine (IBM), became the concern of a group under D. A. Flanders. In anticipation of Mr. Flanders' leaving, B. Carlson became group leader of a new group, T-2, on 14 August 1946.

3.8 Operation Crossroads, which seriously affected the work of some other divisions, did not add to the personnel problems of T-Division. J. O. Hirschfelder, and J. L. Magee, both of whom were with Group T-7 (Damage) until their resignations in the fall of 1945, returned to devote full-time attention to Operation Crossroads problems in the spring and summer of 1946.

3.9 On 20 May 1946, G. Placzek became ill and left Los Alamos on a leave of absence. He could not return to the Project because the high altitude affected his unfavorable heart condition; however, he was not terminated until 9 July 1946. Robert D. Richtmyer, who had transferred from the Patent Group, acted as Division Leader for the Theoretical Division until November 1946 when he became Division Leader.

3.10 In the summer of 1946 a group of consultants aided the work of Theoretical Division. This group included E. Fermi, F. Hoyt, and E. Teller of the University of Chicago; Lothar Nordheim and Gertrud Nordheim of Clinton Laboratories; R. Marshak of the University of Rochester; R. P. Feynman of Cornell University; J. O. Hirschfelder, University of Wisconsin; J. Von Neumann, of the Institute of Advanced Studies, Princeton University; V. Weisskopf, T. Welton, of the Massachusetts Institute of Technology.
With the exceptions of Mr. and Mrs. Nordheim and Mr. Hoyt, all were members of the wartime staff of Los Alamos.

3.11 In the Fall of 1946, S. Ulam, who left Group F-1 in 1945 to join the staff of the University of Southern California, returned to Los Alamos to become Group Leader of a new group whose concern was general mathematical methods. L. Goldstein, formerly of the College of City of New York, and the Division of War

Research, Columbia University, joined the T Division Staff at about the same time.

3.12 A group was set up in the Fall of 1946 under the leadership of R. D. Richtmyer to study the new thermonuclear system proposed by E. Teller, known as the "Alarm Clock" (par. 3.32).

3.13 The group structure of Theoretical Division at the close of the third period, December 1946, was as follows:

T-1	Theory of Dragon	F. Reines
T-2	Computations	B. Carlson
T-3	Super and Radiation Hydrodynamics	R. Landshoff
T-4	Diffusion Theory	C. Mark
T-5	IBM Computations	B. Carlson (Acting)
T-6	Mathematical Methods	S. Ulam
T-9	Alarm Clock	R. D. Richtmyer
T-10	Fundamental Nuclear Physics	L. Goldstein

Effects of Test and Combat Nuclear Explosions

3.14 Interpretation of observations of the July 16, 1945 test explosion at Trinity and of the combat explosions at Hiroshima and Nagasaki made up much of the activity of Theoretical Division in the early fall of 1945. A theory was developed by Group T-1 (Appendix 10,No.10) for estimating the energy release of a fission bomb explosion by consideration of the expansion velocity of the ball of fire in its early stages; this theoretical treatment differed from earlier ones in that it considered the effect of the high-density material of the bomb (and at Trinity, its supporting platform and housing) on the pressure distribution. In an attempt to eliminate the uncertainty (Book VIII, Vol. 2, par. 11.26 concerning the proportion of energy released by a fission bomb which is converted into blast energy, a calculation (Problem M) using the IBM machines was made; the blast energy resulting from the explosion of a fission bomb was found to be about two-thirds that resulting from the explosion of a corresponding amount of TNT

(Appendix 10,No. 11). The final analysis by Group T-1 of the blast and optical data (Appendix 10,No.12) gave as the most probable values based on these data for the nuclear energy release the TNT equivalents of 20,000 tons for Trinity, 15,000 tons for Hiroshima, and 50,000 tons for Nagasaki; the value for Nagasaki was more uncertain than the others.

Radiation Hydrodynamics

3.15 The unexpectedly high yield of the Trinity explosion (Book VIII, Vol. 2, par. 11.27) led to a renewal of the early speculations (Book VIII, Vol. 2, pars. 5.43 to 5.45) about the simplifying assumption (Book VIII, Vol. 2, par. 5.37) of neglect of radiation made in the original efficiency calculations.

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3.19 At the close of the war, Group F-1 (which became Group T-7 on 14 November 1945) was relieved of its responsibilities connected with the design and testing of fission bombs and was able to devote full-time attention to bombs based on thermonuclear processes. E. Fermi summed up existing knowledge on relevent thermonuclear processes in a series of six lectures given in July, August and September 1946. (Appendix 10,No.17) The period of intensive activity of this group came to an end by June of 1946 when the work was curtailed through serious

loss of personnel.

Super Conference

3.20 In April 1946, a conference of members of Group T-7 and other Los Alamos staff members and consultants concerned with the development of thermonuclear bombs took place (par. 1.21). The work on thermonuclear processes was reviewed, and a specific model of a thermonuclear bomb was considered.

3.21 An account of the fundamental physical processes of importance to the thermonuclear bomb is presented in Book VIII, Vol. 2, pars. 13.6 through 13.17, and will not be repeated here. The conference, although it examined this fundamental work for completeness and accuracy, centered its attention on the feasibility of the specific model presented by Group T-7. Proposals and suggestions regarding basic theoretical investigations grew from examination and consideration of this model, which must be described in some detail before reporting the conclusions reached in the conference.

3.22 The model proposed was chosen for amenability to theoretical treatment rather than for engineering practicability or efficient use of precious material. This followed from the purpose of the conference, which was to study the feasibility of thermonuclear bombs in principle, and not to propose designs for actual weapons.

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3.23 Consideration of fundamental principles indicated the operability of a large class of designs having in common the following features:

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Various suggestions were made for means to improve the efficiency of use of tritium and fissionable material and to simplify the engineering of the weapon. But no objection on fundamental grounds to the feasibility of a thermonuclear bomb was presented.

3.27 The members of the conference estimated that the experimental program, development, and testing of the thermonuclear super bomb would require work by a laboratory similar to Los Alamos at its wartime peak for a period of the order of one or two years.

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3.28 Following a recommendation of the conference, Group T-7, soon renamed Group T-3, started a theoretical investigation

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This work proceeded throughout the spring and summer of 1946, although it was hampered greatly by shortage of personnel.

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3.31 By the fall of 1946, continuing loss of personnel and the need for continuing work on radiation hydrodynamics, which was another interest of Group T-3, further curtailed work. In addition, the need for evaluating a new thermonuclear system described below further diluted the efforts of the remaining personnel.

"Alarm Clock"-Thermonuclear System

3.32 In September 1946, E. Teller described a new proposed thermonuclear system incorporating several novel features:

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This proposed weapon was given the name "Alarm Clock"--it might wake up the world.

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before (Chapter I) prevented the Director from giving these staff functions any considerable time, hence, the groups tended to lose their effectiveness.

Formation of D-Division

9.4 When Major Ralph Carlisle Smith, the local Patent Advisor, returned from his security and technical advisory assignment to the Operations Crossroad press ship, U.S.S. Appalachian, he was requested by the Director to consolidate the technical staff groups, other than the health group, into a division, and ultimately to take over the duties of an Assistant Director. On 21 August 1946, the Director announced the formation of the Documentary (D) Division with the responsibility for Technical Series editorial work; the Document Room; the Technical Library; editorial revision, review and control of reports; information dissemination; declassification; history; and various other technical services, with Major Ralph Carlisle Smith as Head and Herbert I. Miller as alternate. (Appendix 10, No. 29) Although the contractor did not assume responsibility for Patent control, this being the delegated responsibility to Smith from the OSRD Patent Advisor, Captain R. A. Lavender, U.S.N. Ret., this control was exercised in the Documentary Division as a dual responsibility of its leader. Later when Mr. E. J. Demson left the project in 1946, Major R. C. Smith also accepted the project responsibilities of an Assistant Director, particularly the legal duties of Mr. Demson. This new arrangement removed a considerable load from the Director and by reorganization of the accumulated staff groups, so as to use the available professional personnel in several phases of the work, it was possible to improve the services of the staff groups with a smaller number of employees. The responsibilities were generally divided as follows: Patents and Legal, Library and Document Room, History and Technical Series, Report Editing - Review, Classified Information Dissemination, Declassification, Drafting (Patents, Reports and Miscellaneous), Technical Illustrations and Art Work.

9.5 The group organization for D-Division during 1946 is shown in Appendix 8A.

9.6 Most of the functions of D-Division have been covered in the discussion under the technical staff groups of **Book VIII**, Vol. 2, par. 3.82 to 3.87 and 3.123 to 3.128. There are few phases however which are new and which merit additional comment.

THE TECHNICAL SERIES

9.7 In conformity with other sections of the Manhattan Project, a program was initiated to record, in accessible and edited form, the technical knowledge and gains of the laboratory. In principle, it was proposed to prepare a "Handbuch der Los Alamos" in analogy with the famous Handbuch der Physik (Appendix 10, No. 30). Titles for seventeen volumes were established in August 1945, as well as volume, and, in some cases, chapter and section editors. Difficulty in establishing a title for the overall work arose. The original name "Handbuch der Los Alamos" was misleading in its English translation, so the title Los Alamos Encyclopedia was substituted. But inasmuch as it was decided that "encyclopedia" implied an alphabetical arrangement, that too was discarded and the "Los Alamos Technical Series" was finally chosen. (Appendix 8B).

9.8 Dr. Hans Bethe and Dr. David Inglis were originally responsible for this compilation with the following staff of volume editors:

Volume No.	Title	Editor
0	"Relation Between the Various Activities of the Laboratory"	S. K. Allison
1	"Experimental Techniques"	Darol K. Froman
2	"Numerical Methods"	Eldred C. Nelson
3	"Nuclear Physics"	R. R. Wilson
4	"Neutron Diffusion Theory"	George Placzek
5	"Critical Assemblies"	O. R. Frisch
6	"Efficiency"	V. F. Weisskopf

7	"Blast Wave"	Hans. A. Bethe
8	"Chemistry of Uranium and Plutonium"	Joseph Kennedy
10	"Metallurgy"	Cyril S. Smith
11	"Explosives"	G. B. Kistiakowsky
12	"Implosion"	R. F. Bacher
13	"Theory of Implosion"	R. E. Peierls
21	"The Gun"	F. Birch
22	"Fuzes"	R. R. Brode
23	"Engineering and Delivery"	N. F. Ramsey
24	"Trinity"	K. T. Bainbridge

9.9 Only Volume 1 and 2 have been considered completely declassifiable under the existing standards. However, a substantial portion of the information in some of the others will eventually be declassifiable and, with the exception of the weapon data, the remainder was to be distributable throughout the Manhattan Project for its general benefit.

9.10 Shortly after the initiation of the program, Dr. David Hawkins and Robert R. Davis were assigned the responsibilities of the Technical Series because of the imminent departure from Los Alamos of both Dr. Bethe and Dr. Inglis. When Dr. Hawkins left the project in the late summer of 1946, Robert R. Davis took over the detail as a Group Leader in D-Division.

9.11 The Technical Series compilation has proceeded at a slow rate since the time of its inception. Exceptional delays resulted because many individuals were reluctant or unable to continue obligations, taken on while at Los Alamos, after their departure. A more understandable difficulty was experienced by active project personnel who were faced with the problem of conducting an active technical program while writing about one accomplished in the past.

9.12 By January 1947, Vol. 0 and 22 were completed and issued, and two-thirds of Vol. 1 had been issued.

Appendix Number 7

Description of Technical Series

Title and brief description of each volume being written for the Los Alamos Technical Series. (par. 9.7).

CONTENTS OF THE LOS ALAMOS TECHNICAL SERIES

Volume Number	Title and Description	Editor
0	"Relation Between the Various Activities of the Laboratory" (A general survey of the work of the Los Alamos Laboratory during the war years, with particular emphasis upon the problems of the critical mass and of the efficiency. In addition to a discussion of the gun and implosion type bombs, the volume contains a section dealing with other methods of attaining the explosive release of nuclear energy.)	S. K. Allison
I	"Experimental Techniques" (A description of the experimental physics equipment used by the Los Alamos Laboratory. The volume has three parts: the first dealing with electronics; the second with ionization chambers and counters; and the third with miscellaneous techniques used in obtaining physical measurements.)	Darol K. Froman
II	"Numerical Methods" (A survey of the methods used in performing numerical calculations of various types of equations by hand computation and with the use of International Business Machines.)	Mildred C. Nelson
III	"Nuclear Physics" (A comprehensive report of nuclear physics measurements made by the Los Alamos Laboratory, together with theoretical evaluations of results and a detailed discussion of the fission process.)	R. R. Wilson
IV	"Neutron Diffusion Theory" (The theory of diffusion with and without a change in velocity, including a discussion of statistical fluctuations.)	George Placzek

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Volume Number	Title and Description	Editor
V	"Critical Assemblies"	O. R. Frisch
	(A report of critical mass experiments made at Los Alamos with uranium-235 and plutonium assemblies for various tampers. A theoretical discussion is included.)	
VI	"Efficiency"	V. F. Weisskopf
	(A theoretical method for calculating the energy release of a nuclear explosion.)	
VII	"Blast Wave"	Hans A. Bethe
	(A study of blast wave phenomenon, both from a theoretical and an experimental point of view. Particular emphasis is placed upon the behavior of the blast wave in large explosions, and an effort has been made to interpret blast data from studies made at Trinity, Hiroshima and Nagasaki.)	
VIII	"Chemistry of Uranium and Plutonium"	Joseph Kennedy
	(A survey of the problems concerned with the chemical purification and recovery of uranium and plutonium, together with a discussion of the preparation of their various compounds and of the analytical methods used in their study.)	
X	"Metallurgy"	Cyril S. Smith
	(A report on the metallurgy of uranium, plutonium and all other metals fabricated by the CMR Division.)	
XI	"Explosives"	G. B. Kistiakowsky
	(A survey of the experimental work done by the Los Alamos Laboratory on the behavior of explosives and on the techniques of explosive casting.)	

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Volume Number	Title and Description	Editor
XII	"Implosion"	R. F. Bacher
	(A report on the experimental implosion program from the early tests to the development of the Trinity bomb. The volume covers work done on polonium, radio-barium and radio-lanthanum.)	
XIII	"Theory of Implosion"	R. E. Peierls
	(A theoretical survey of the implosion process. The volume contains discussions of shock hydrodynamics, equations of state and various implosion designs.)	
XXI	"The Gun"	F. Birch
	(A survey of the experimental gun program from the early tests to the development of the Hiroshima bomb. This volume includes design specifications and a discussion of the interior ballistics of the gun.)	
XXII	"Fuzes"	R. B. Brode
	(A study of work done by the Los Alamos Laboratory in designing detonating fuze assemblies for the implosion and gun type bombs.)	
XXIII	"Engineering and Delivery"	N. F. Ramsey
	(The history of Project "A" together with a discussion of engineering problems encountered in the delivery program. Particular attention has been given to the mechanical design and assembly of the Model 1561 implosion bomb.)	
XIV	"Trinity"	K. T. Bainbridge
	(A complete report on the 100 ton TNT calibration and rehearsel shot and the July 16, 1945 atomic bomb test at the Alamogordo Air Base. The volume includes both experimental and theoretical discussions of the various phases of the test. A large appendix contains all pertinent Trinity memoranda and all LA and LAMS reports concerning the Trinity explosion.)	

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Appendix Number 10

File References

Ref. No.	Item	Par. No.
1	The following documents present various technical aspects of the Crossroads Operation. Copies are located in the Los Alamos Document Room, Los Alamos, New Mexico.	1.45

Number	Title	Date	Author
LAMS-430	Crossroads Technical Instrumentation Report: Timing Signals (Test A & B)	9/1/46	H. G. Weiss
LAMS-428	Crossroads Technical Instrumentation Report: Air-dropped condenser gauges.	9/1/46	J. C. Wieboldt
LAMS-428A	Supplement - Crossroads Technical Instrumentation Report: Air-dropped condenser gauges.	9/1/46	J. C. Wieboldt
LA-613	Nuclear efficiencies of the Bikini shots as determined by the Radio-chemical Method.	11/26/46	W. Rubinson
LAMS-431	Crossroads Technical Instrumentation Report: Gamma Timing Radio Link (Test B)	9/1/46	T. D. Cabot A. S. Jerrems
LAMS-378	Manual for Pit Assembly of Nagasaki Type Bomb.	3/22/46	R. E. Schreiber
LAMS-381	Pit Catalog; Destination Kit.	5/7/46	R. E. Schreiber
AM-2663	List of Reports Prepared by Director of Ship Material Organization. (Operation Crossroads).	n.d.	United States War and Navy Depts. Joint Task Force One
AM-2664	List of Reports to the Technical Director, Joint Task Force One. (Operation Crossroads)	n.d.	United States War and Navy Depts. Joint Task Force One
AM-2363	Catalog of Atomic Bomb Photography for Able Day, 1 July 1946 and Baker Day 25 July 1946	n.d.	United States War Dept. Army Air Forces

AM-2360	Crossroads Signals (Transcription).	10/11/46	M. G. Holloway
AM-2443	Overseas History B-Division Measurement Section.	8/15/46	H. M. Lehr M. G. Holloway
AM-2483	Operations Crossroads, Official Report.	n.d.	United States War Dept., Army Air Forces
LA-550	Crossroads Handbook of Explosion Phenomena	4/9/46	S. T. Cohen; J. Hirschfelder; Mac H. Hull; J. L. Magee
LA-577	Formation and Rise of Smoke Clouds from Explosions	6/18/46	S. T. Cohen
LAMD-8	Crossroads Technical Planning for Bomb Section	3/7/46	
LAMS-432	Crossroads Technical Instrumentation Report; Firing Signals (Test B)	9/1/46	H. J. Hall
LAMD-52	History of Los Alamos B-Division	4/30/46	M. G. Holloway
LAMS-429	Crossroads Technical Instrumentation Report; Gamma Ray Timing (Test B)	9/1/46	Norris Nereson
LA-620	Capture-to-fission Ratio of Pu-239 for Bomb Neutron Spectrum.	2/3/47	W. Rubinson

2 Code of Classifications and Salaries prepared by the Personnel Group and approved in February 1946. A copy of these regulations is on file in the Central Mail and Records Section, Los Alamos, New Mexico. 2.14

3 Letter from Major R. I. Newcomb, 22 January 1946 to the War Department Wage Administrator on the subject of Special Bonus on Contract W-7405-Eng-36 (Test Personnel Only). This basic communication was approved by first indorsement from John R. Ebersold on 25 January 1946. A copy of this correspondence is on file with the Assistant Area Manager, for the Los Angeles Office, Los Alamos Project Office, Los Alamos, New Mexico. 2.16

4 Letter of 28 January 1946 from Dr. N. E. Bradbury to automobile manufacturers requesting allotment of cars for Los Alamos. Copy located in Central Mail and Records Group, Los Alamos, New Mexico. 2.22

Ref. No.	Item	Par. No.
5	Letter of 23 July 1945 from Lt. William A. Farina to Lt. Col. S. L. Stewart on subject of Property Control at Project Y. A copy is located in the AEC Mail and Record Section, Los Alamos, New Mexico.	2.50
6	Property Control Manual issued by Property Section to Division and Group Leaders. Copies are on file in the Supply and Property Group, Los Alamos, New Mexico.	2.52
7	Inspection Report, 28 August 1945 from Lloyd E. Blanchard, Consulting Engineer to General L. R. Groves. A copy of this report is on file at AEC Mail and Record Section, Los Alamos, New Mexico.	2.58
8	Letter from Dr. Wright Langham to Capt. James F. Nolan, 8 March 1946 on the subject of: Violations of Health Passes. A copy of this correspondence is on file in the Health Group files, Q Building, Los Alamos, New Mexico.	2.77
9	A copy of the Master Policy FD-502 contract, June 1945, is on file in the Business Office, Los Alamos, New Mexico.	2.124
10	LA-516 Measurement of Nuclear-Bomb Efficiency by Observation of the Ball of Fire at Early Stages, by Hans Bethe and Karl Fuchs, written 20 February 1946. A copy is on file in the Document Room, Los Alamos, New Mexico.	3.14
11	LAMS-300 Progress Report of Theoretical Physics Division for September 1945, by Hans Bethe. A copy is filed in the Document Room, Los Alamos, New Mexico.	3.14
12	LAMS-405 Progress Report for Theoretical Physics Division for May and June 1946, by R. D. Richtmyer. A copy is on file in the Document Room, Los Alamos, New Mexico.	3.14
13	LA-623 Radiation Hydrodynamics Part V, by Rolf Landshoff, 10 February 1947. A copy is filed in the Document Room, Los Alamos, New Mexico.	3.15
14	LAMS-273 by Hans Bethe, Progress Report of the Theoretical Physics Division for July 1945. A copy is on file in the Document Room, Los Alamos, New Mexico.	3.16
15	LA-590 Rate of Reaction in a Nuclear Fission Bomb Stopped by Depletion Alone, by E. Baroody, 24 July 1946. A copy is on file in the Document Room, Los Alamos, New Mexico.	3.16
16	LAMS-287 by Hans Bethe, Progress Report of the Theoretical Physics Division, August 1945, 26 September 1945. A copy is filed in the Document Room, Los Alamos, New Mexico.	3.18
17	LA-344 Six Lectures by E. Fermi, written by D. Inglis. Part 1 - Ideal Ignition Temperature, 27 July 1945 Part 2 - Electron Temperature Lag. Secondary Reactions, 7 August 1945	3.19

Ref. No.	Item	Par. No.

Part 3 - Addition of Tritium, 18 August 1945
Part 4 - Time Scale. Radiation Cooling. 11 September 1945
Part 5 - Thermal Conduction as Affected by a Magnetic Field, 17 September 1945
Part 6 - Loss by Particle Ranges, 9 October 1945

Copies of these reports are located in the Document Room, Los Alamos, New Mexico.

18 — Letter from Dr. R. R. Wilson, 31 October 1945, to Dr. N. E. Bradbury on the Subject of Combining R and F Divisions. A copy of this letter is on file in Central Mail and Records Group, Los Alamos, New Mexico. — 4.1

19 — The 40" Cyclotron was purchased from Harvard College by the Los Alamos Laboratory, on Contract W-7401-Eng-31, for $200,000. The Cockcroft-Walton accelerator was purchased from the University of Illinois, on Contract W-7401-Eng-32, for $22,000. The "short tank" Van de Graaff was purchased from the University of Wisconsin, on Contract W-7401-Eng-33, for $80,000. — 4.29

20 — Letter from Major General L. R. Groves to Dr. N. E. Bradbury 12 December 1946, confirming telephonic authority of January 1946 to construct Van de Graaff. A copy of this document is located in the Laboratory Director's files, Los Alamos, New Mexico. — 4.42

21 — Letter from Dr. J. L. McKibben to Dr. N. E. Bradbury, 11 October 1946, on the subject of the history of the 8 Mev Van de Graaff Program. A copy is on file at Central Mail and Records Group, Los Alamos, New Mexico. — 4.46

22 — LADC-72 Distribution of Neutrons in the Atmosphere by H. M. Agnew, W. C. Bright, and Darol Froman. This was later published in Physical Review, 1 August 1947, Vol. 72, No. 3. — 4.67

23 — A complete historical record on the radiation accident 31 August 1945 fatal to Harry K. Daghlian, is on file in the Central Mail and Records Group, Los Alamos, New Mexico. — 5.16

24 — The complete case history of the accident and death of Louis Slotin, 21 May 1946, is on file in the Central Mail and Records Office, Los Alamos, New Mexico. — 5.20

25 — LAMS-452 The Pajarito Safety Manual, by Raemer Schreiber 3 December 1946. A copy is located in the Document Room, Los Alamos, New Mexico. — 5.23

26 — LAMS-367 Experiments on a High Efficiency Fast Neutron Counter, by Christopher Wright and Volney C. Wilson, dated 9 April 1946. A copy is located in the Document Room, Los Alamos, New Mexico. — 5.27-3

Ref No.	Item	Par. No.
27	LA-531 Time-Space Relationships by Julian Mack, 2 April 1946; LA-509 Gamma Radiation at Hiroshima, by Donald C. Livingston, 10 December 1946. Copies of these documents are on file in the Document Room, Los Alamos, New Mexico.	5.56
28	Letter from Dr. Eric Jette to Dr. N. E. Bradbury, 10 April 1946, on the subject of Chemical and Metallurgical Research at Site Y. Original copy is located in Central Mail and Records Group, Los Alamos, New Mexico.	6.8
29	Complete correspondence from Dr. N. E. Bradbury, Major General L. R. Groves and Captain R. A. Lavender approving the establishment of the Documentary Division with Major Ralph Carlisle Smith, Division Leader, and final directive from Dr. Bradbury announcing the formation of this new division, 21 August 1946. Located in Central Mail and Records Group, Los Alamos, New Mexico.	9.4
30	Letter from H. A. Bethe, 21 August 1945, gives the tentative plan for the Los Alamos Handbook, with suggested topics. A copy is filed in Central Mail and Records Group, Los Alamos, New Mexico.	9.7
31	The Tolman Report of December 1945, recommended the program of declassification adopted by the Manhattan Engineer District. A copy of this report is on file in the Laboratory Director's Office, Los Alamos, New Mexico.	9.16

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BOOK VIII, VOLUME 2

PROJECT "Y" HISTORY

TECHNICAL

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PREFACE

Project Y, the Los Alamos Project, has been one of a group of organizations known collectively as the Development of Substitute Materials Project, devoted to the wartime development of the atomic bomb. This branch of the DSM organization was created early in the year 1943. During the period of its existence it has been the center of activities connected with bomb development and production, as distinguished from the development and production of nuclear explosive materials.

The history of all DSM activities possesses a peculiar interest and importance, not only because of the remarkable achievements and potentialities of nuclear technology, but also because of the wartime character and motivation of its initial development. Because of its large social cost, a scrupulous accounting of the entire venture is evidently required. Project Y has been, of itself, small compared to the other DSM projects. It has, however, occupied a crucial position. The wartime success of the entire undertaking has depended upon its success.

The nature of the present chronicle of Los Alamos is thus determined by the requirement that there exist a careful accounting of its technical, administrative and policy-making activities. This document is a record, not an interpretation of events. Within the limitations thus implied, however, it has not been forgotten that the events recorded have taken place within a wider context, the evolution of organized scientific research and of world technology. The problems of organization and policy that lie here, sharpened by the advent of control over nuclear energies, will call for the most searching interpretation and analysis. It is hoped that in this record of fact

it does come at the time of an extensive administration reorganization. The real purpose of this division is to permit some chance to summarize and connect activities which, although constantly interrelated in practice, must be written about in separate chapters. And although no distinct separation into phases is possible, the date chosen marks as well as any the transition at Los Alamos from research to development, from schematization to engineering.

At this place I wish to acknowledge the assistance I have received from many members of the Los Alamos Laboratory. In particular I wish to thank the following: Major J. A. Ackerman, S. K. Allison, E. Anderson, K. T. Bainbridge, C. L. Critchfield, P. Duffield, A. C. Graves, E. Graves, L. H. Hempelmann, T/4 A. U. Henshey, H. I. Miller, E. Morrison, P. Morrison, N. H. Ramsey, F. Reines, Major Ralph Carlisle Smith, and R. Taschek. These persons have materially helped me in gathering data, in drafting various sections of the report, or in extensive criticism of earlier drafts. I wish especially to thank Emily Morrison and Priscilla Duffield for ingenious researches in the records of an organization that was frequently too busy to be concerned with posterity. Mrs. Morrison has prepared the graphical material, has drafted several of the chapters, and has given invaluable general assistance. Finally it must be made clear that all errors of fact in this record are the sole responsibility of the author.

David Hawkins

August 6, 1946

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scattering is not isotropic, it is also necessary to specify the angular distribution of scattered neutrons. All of these cross-sections, moreover, depend upon the nucleus involved and the energy of the incident neutron. Calculation of critical mass and efficiency depends upon all of these cross sections, as well as upon the number of neutrons per fission and density of material. It was clear that to obtain such measurements with the necessary accuracy would entail an elaborate program of experimental physics and a comparable effort of theoretical physics to make the best use of information obtained.

1.37 Effects of Tamper. The effect of tamper is not only to decrease the critical mass by reflecting neutrons back into the active material, but also to increase the inertia of the system and therefore the time during which it will remain in a supercritical state. These gains are somewhat lessened by the longer time between fissions of neutrons reflected back from the tamper. The lengthening of the time is caused not only by the longer path, but also by a loss of energy through inelastic scattering in the tamper. Calculations of the effect of tamper material depend thus on the absorption and scattering cross-sections of tamper material. It is interesting to note that Serber's early calculations gave, for a tamper of U^{238}, a critical mass for U^{235} of 15 kilograms, and for Pu^{239} of 5 kilograms. Both figures are correct to within a reasonable error. This may be regarded as in part good fortune, since many of the assumptions made were rough guesses. It nevertheless serves to illustrate the advanced state of basic theory at the time.

1.38 Efficiency, Detonation and Predetonation. Some indication has been given above of the basis for efficiency calculations. The outcome of such calculations was to show that efficiencies would be low. There is, moreover, another essential factor in efficiency, connected with the problem of assembly and detonation, the early discussion of which is reviewed below.

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that are involved.

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1.41 Gun Assembly, Initiator. The considerations of the last section indicate the magnitude of the assembly problem: to initiate properly and reliably a reaction whose entire course occurs in a fraction of a microsecond, subject to the complementary needs for high-velocity assembly and low neutron background. As was mentioned above, the principal source of neutron background is the (α, n) reaction in light-element impurities. To lower this background would require a strenuous program of chemical purification.

1.42 The most straightforward early proposal for meeting these difficulties was the method of gun assembly; the general proposal was that a projectile of active and tamper material, or of active material alone, be shot through or laterally past a target of active material and tamper. For U^{235} both the chemical purity requirements and the needed velocity of assembly were attainable by known methods. Many difficult engineering problems were evidently involved, but they did not appear as insuperable. For Pu^{239} the requirements for purity and speed were both somewhat beyond the established range. It seemed, however, that by rather heroic means they could be met.

1.43 High-velocity assembly and the reduction of the neutron background would decrease the probability of predetonation; they would also decrease the probability of detonation at the desired time. Unless material could be assembled so as to remain in its optimum configuration for a considerable length of time, there was a danger that "postdetonation" too would give low efficiency, or that the system would pass through its supercritical state without detonation occurring at

all. To overcome this difficulty it would be necessary to develop a strong neutron source that could be turned on at the right moment. Theoretically feasible schemes for such an initiator had been conceived, but their practicability was not assured.

1.44 Autocatalysis, Implosion. Two other methods of assembly had been proposed, and it was a part of the early program to investigate them. One of these was a self-assembling or autocatalytic method, operating by the compression or expulsion of neutron absorbers during the reaction. Calculation showed that this method as it stood would require large quantities of material and would give only very low efficiencies.

1.45 The second alternative method was that of implosion. In its first concrete form the proposal was to blow together a subcritical hollow spherical shell of active material and tamper by detonation of a surrounding layer of high explosive.

1.46 Both these methods had the great disadvantage, in a short-term war program, of being mere proposals, without any previous engineering implementation such as existed in the field of gun design.

1.47 The Deuterium Bomb or "Super". There existed, at the time of the April Conference, one other important proposal to which considerable thought and discussion had been given in the previous months. This was a proposal to use the fission bomb as a means for initiating a nuclear reaction of a different type from that involved in the fissioning of heavy-element nuclei. Fissioning, the disruption of nuclei with liberation of energy, is a somewhat anomalous reaction restricted to the heaviest nuclei. Among the lighter elements the typical exoergic (energy-producing) reaction is the building up of heavier nuclei from lighter ones. For example two deuterium (hydrogen^2) nuclei may combine to form a helium^3 nucleus and a neutron, or a tritium nucleus (hydrogen^3) and a proton. The energy that is liberated goes into kinetic energy and radiation. If such a reaction occurs in a

mass of deuterium, it will spread under conditions similar to those that control ordinary thermochemical reactions. Hence the reaction is called thermonuclear. The cross-section for a reaction between two deuterium nuclei is strongly dependent upon the energy of the nuclei. At low energies the probability that the reaction will occur is very small. As the temperature of the material increases, the reaction becomes more probable. Finally a critical temperature is reached, where the nuclear reactions in the material just compensate for various kinds of energy loss, such as heat conduction and radiation. The thermonuclear reaction is in detail more complicated than has been indicated, because of the presence of a variety of secondary reactions.

1.48 Among available materials, deuterium has the lowest ignition temperature. This temperature was estimated to be about 35 kilovolts (about 400 million degrees), and is actually somewhat lower. Once ignited, deuterium is about 5 times as energy-productive per unit mass as U^{235}. Thus one kilogram of deuterium equals about 85,000 tons of TNT equivalent. Since it is not more difficult to ignite a large than a small mass of deuterium, and since it is more cheaply produced in usable form than either U^{235} or Pu^{239}, the proposed weapon, using a fission bomb as a detonator and deuterium as explosive, could properly be called an atomic super-bomb. The development of this super-bomb was perforce secondary to that of the fission bomb; on the other hand its potentialities were so great that research toward its development could not be completely neglected.

1.49 It should be mentioned at this point that in the early period of the project the most careful attention was given to the possibility that a thermonuclear reaction might be initiated in light elements of the Earth's atmosphere or crust. The easiest reaction to initiate, if any, was found to be a reaction between nitrogen nuclei in the atmosphere. It was assumed that only the most energetic of several possible reactions would occur, and that the reaction cross-sections were at the maximum values theoretically possible. Calculation led

to the result that no matter how high the temperature, energy loss would exceed energy production by a reasonable factor. At an assumed temperature of three million electron volts the reaction failed to be self-propagating by a factor of sixty. This temperature exceeded the calculated initial temperature of the deuterium reaction by a factor of one hundred, and that of the fission bomb by a larger factor.

1.50 The impossibility of igniting the atmosphere was thus assured by science and common sense. The essential factors in these calculations, the Coulomb forces of the nucleus, are among the best understood phenomena of modern physics. The philosophic possibility of destroying the earth, associated with the theoretical convertibility of mass into energy, remains. The thermonuclear reaction, which is the only method now known by which such a catastrophe could occur, is evidently ruled out. The general stability of matter in the observable universe argues against it. Further knowledge of the nature of the great stellar explosions, novae and supernovae, will throw light on these questions. In the almost complete absence of real knowledge, it is generally believed that the tremendous energy of these explosions is of gravitational rather than nuclear origin.

1.51 More immediate and less spectacular global dangers to humanity arise from the use of thermonuclear bombs, or even fission bombs, in war: principally from the possible magnitude of destruction and from radioactive poisoning of the atmosphere (13-29).

1.52 Damage. So far we have reviewed only the early discussion of energy release. Since, however, the purpose of the project was to produce an effective weapon, it was necessary to compare the atomic bomb with ordinary bombs, not merely as to energy release, but more concretely as to destructive effects. Damage could be classified under several headings: The psychological effects of the use of such a weapon; the physiological effects of the neutrons, radioactive material and radiation produced; the mechanical destruction produced by the

shock-wave of the explosion. Estimation of the first was not of course within the means or jurisdiction of the project. Of the second, it was estimated that lethal effects might be expected within a radius of one thousand yards of the bomb. The radioactivity remaining might be expected to render the locality of the explosion uninhabitable for a considerable period, although this effect would depend on the percentage of activity left behind, which was as yet an unknown quantity. The principal damage would be caused by the mechanical effects of the explosion. These effects were difficult to estimate. Some rough data on the effects of large explosive disasters were available. More reliable information was available concerning the effects of small high explosive bombs, but it was not known for sure how these effects should be scaled upward for high-energy atomic bombs. Serber's report gives an estimate of a destruction radius of about two miles for a 100,000 ton bomb. Members of the British mission who came to the project somewhat later were able to add to the understanding of this topic from their national experience and their research of recent years.

DEVELOPMENT OF PROGRAM

Introduction

1.53 From the previous outline of the state of knowledge at the beginning of the Bomb Project, it is clear that the greatest problems were bound to arise on the side of development and engineering. There was still much work to be done in nuclear physics proper, but enough was known to eliminate great uncertainties from this side of the picture. It should not be concluded, however, that the stage of research was past its prime, to be dominated in turn by problems of application. The normal meanings attached to "research", "development", and "engineering" are altered in the context of wartime science generally; that is particularly true of the Atomic Bomb Project. Two features have determined its general character. The first is the domination of research schedules by production schedules; the second is the nature of the weapon itself. Time schedules for the

production of U^{235} and Pu^{239} were such that the laboratory had before it about two years until explosive amounts of these materials would be available. After that time every month's delay had to be counted as a loss to the war. The practical consequence was that many kinds of information had to be gotten at the earliest possible date, with greatest difficulty, even though at a later date the same information could be gotten more easily and reliably. The micro-metallurgy of plutonium was investigated at Chicago, for example, because it was vital, among other things, to know the density of the new material as soon as possible; the first measurement was made with great labor, from a sample of only a few micrograms. The value of such information depended upon its capacity to influence decisions which could not be postponed. This meant a heavy dependence upon theory and upon measurements of the type needed to answer theoretical questions. To some extent reliance was placed upon theoretical anticipations because of the all-or-none character of the weapon. A purely experimental nuclear explosion would involve the dissipation of at least one critical mass of material that might have been used against the enemy. If tests were to be made at all, only one or two would be possible. For so small a number of tests to be meaningful, they would have to have a large a priori probability of success. Although this question of tests was not decided at the beginning of the project, certain general implications were clear: The bomb's component parts and phases of operation had to be designed and tested separately, with reliance upon theory to supply a picture of its integral operation.

1.54 It is not remarkable, in the light of what has been said, that the initial program, personnel and equipment of the laboratory gave it the appearance of a purely research organization. That it had this appearance was partly a matter of previous history; nuclear research was the most advanced part of the program, and its personnel and equipment were most easily available. In part, however, the research character of the organization was a matter of

considered policy. Normally, the engineer is the "practical man" who translates ideas into practice. Here, not only the ideas but also the standards of practice were new. To keep the center of policy in the research group was not to minimize the importance of the engineering work, but to emphasize its difficulty. Secondary problems undeniably arose from this policy, which displaced the engineer from his normal position, and only through trial and error created for him a new place in the division of Project labor.

Theoretical Program

1.55 Enough has been said to indicate the central position in the laboratory of its theoretical program. As it emerged from the conferences this program had as its main goal to analyse the explosion, and develop the associated techniques of calculation; to give nuclear specifications for the bomb with increasing reliability and accuracy as new physical data became available. Calculations had to be made for three materials: U^{235}, Pu^{239}, and also a new compound, a hydride of uranium, which seemed to have certain advantages over metallic uranium as a bomb material. Calculations also had to be made for a variety of shapes of the active mass, and for different combinations of bomb and tamper material. For critical-mass calculations the theory of neutron-diffusion in bomb and tamper had to be refined, and account taken of the energy distribution of fission neutrons, as well as the dependence of nuclear cross-sections upon those energies. For efficiency calculation, further study was needed of the hydrodynamics of the explosion, taking account of the effects of the large amounts of radiation liberated in the process. Further investigation was needed of the problems connected with time of assembly, detonation and predetonation.

1.56 In addition to these problems relating to bomb design, the theoretical program included a variety of analyses and calculations connected with the experimental program, ranging from ordinary service calculations to the design of a slow chain-reacting unit with U^{235}-enriched uranium.

1.57 The program included, finally, the further investigation of bomb damage, of the possibility of autocatalytic methods of assembly, and the proposal to amplify the effect of fission bombs by using them to initiate thermonuclear reactions.

Program of Experimental Physics

1.58 The program of experimental physics formulated during and immediately after the conferences falls under two main headings: Detailed and integral experiments. Detailed or differential experiments are those which attempt to observe the effects of isolated nuclear phenomena. From a sufficient number of experimental data gained in this way, an integral picture of the operation of the bomb could be built up within a framework of theory. Integral experiments, on the other hand, were - at least in their early conception - attempts to duplicate in experimental arrangement some of the overall properties of the bomb. Experiments of the two kinds were intended to supplement each other wherever possible; on the one hand to sharpen the interpretation of integral experiments, on the other to show up possible omissions of elements from the detailed picture. In practice, it has proved extremely difficult to devise integral experiments which in any way duplicate the conditions obtaining in the bomb. The integral experiments that have been performed have had rather the effect of checking theory in situations in some ways similar to the bomb.

1.59 A brief outline of the program as first developed will serve also to indicate the state of experimental knowledge carried over from the previous period.

1.60 Differential experiments:

Neutron Number: The average number of neutrons per fission had never been measured directly, although the Chicago Project had measured the number of neutrons from U^{235} per thermal neutron absorbed. The number of neutrons per fission could be calculated from this measurement and from the ratio of fissions to captures, which, however, was not known reliably in the region of

thermal energies. The neutron number of Pu^{239} was completely unknown although it was expected to differ but little from that of U^{235}. The first experiments planned were in fact measurements of neutrons from Pu^{239}.

1.61 These latter measurements were of intrinsic importance, and were needed at the earliest date possible to confirm the wisdom of heavy commitments already made for the production of plutonium in quantity.

1.62 Fission Spectrum: The energy range of neutrons from the fission of U^{235} had been investigated by the British, and by the Rice Institute and Stanford sub-projects. These measurements suffered from the large dilution of isotope 235 by 238 in normal uranium. Work had already been begun at Minnesota with enriched material, and this program was to be continued at Los Alamos.

1.63 Fission Cross Sections: Fission cross-sections had been measured by the sub-project under N. P. Heydenberg at the Department of Terrestrial Magnetism of Carnegie Institute, by McKibben's group at Wisconsin, and by Segre's group in Berkeley. These measurements - for U^{235} - covered the neutron energy range above 125 kev, and the range below two ev. When the curve for fission cross-sections over the high-energy range was extrapolated downward, a figure was obtained for thermal energy that was much larger than the cross-section actually observed. Since the extrapolated region covered the important range of neutron energies in a bomb of uranium hydride, measurements were planned to investigate cross-sections at these intermediate energies, and resolve the apparent anomaly. Fission cross-sections of Pu^{239} were already known at thermal energies and at a few high energies. Here also measurements were planned to cover the entire range of energies up to about 3 Mev.

1.64 Delayed Neutron Emission: Experiments at Cornell had shown that there was no appreciable delay beyond ten microseconds in the emission of neutrons from fission; one of the initial experiments planned at Los Alamos was to push

this time down to a tenth of a microsecond; on theoretical grounds it was expected that the number delayed even for this time would be small.

1.65 Capture and Scattering Cross-Sections: At the beginning of the project little was known about capture and scattering cross-sections. Some measurements of capture and inelastic scattering cross-sections had been made at Chicago for normal uranium. Experiments by the Minnesota group had given values for elastic and inelastic scattering in uranium for high energies. The Wisconsin group had measured large-angle elastic scattering in a number of potential tamper materials. Capture cross-section measurements were made by Segre at Berkeley. The principal work planned for the Los Alamos Laboratory was on the scattering and absorption cross-sections of U^{235} and Pu^{239}, and the capture and scattering cross-sections of various tamper materials.

1.66 One new type of scattering measurement, not previously undertaken, was planned for this laboratory. This was the measurement of scattering into different solid angles. When so averaged as to give the effective scattering in a given direction, this average is the so-called transport cross-section.

1.67 Integral Experiments: Certain integral experiments had been performed at Chicago, in connection with the development of the slow neutron chain-reacting pile. These were not of direct interest to the bomb project. Two types of integral experiments were however planned in the early experimental physics program:

1.68 Integral Tamper Experiments: Several experiments were planned to measure the scattering in potential tamper materials; these were designed to imitate the scattering properties of a tamper in the actual bomb.

1.69 The "Water Boiler": At the April Conferences there was some discussion of the possibility of constructing a slow chain-reacting unit, using uranium with enriched U^{235} content in water solution. The construction of such

a unit would provide a useful neutron source for experimental purposes, and would also give practice in the operation of a super-critical unit. The decision to make such a unit was not reached until some time later.

1.70 Experimental Techniques: A large subsidiary program was called for, to investigate techniques for producing and counting neutrons of a given energy, for measuring fissions in various materials, and for measuring neutron-induced reactions other than fission. The systematic recording of nuclear properties entailed by the experimental program required both accuracy and standardization of a number of difficult techniques; the program of instrumentation represented therefore a major activity of the laboratory.

Program of Chemistry and Metallurgy

1.71 During the course of the DSM Project a large amount of research had been carried out on the chemistry and metallurgy of uranium. The micro-chemistry and micro-metallurgy of plutonium were investigated at Chicago as soon as small amounts of the material were available. The chemical investigations were necessary as a basis for designing methods of recovering plutonium from the pile material and "decontaminating" it, i.e., separating it from radio-active fission products.

1.72 At the beginning of the Los Alamos project the exact division of labor between its chemistry laboratory and other laboratories had not been settled. There were objective difficulties and uncertainties of program. It was not known whether U^{235}, Pu^{239} or both would be used, or whether the bomb material would be metal or compound. U^{233}, producible from thorium by a process of "breeding" similar to that by which Pu^{239} is made from U^{238}, was also a possibility. Mechanical requirements for the bomb material could not yet be specified. Here also a characteristic difficulty appeared, in that the time for research with gram and kilogram amounts of material would have to be as short as possible, in order to avoid delay in bomb production.

1.73 One certainty was a schedule of purity requirements for U^{235} and Pu^{239}. Because of the large alpha radioactivity of the latter substance, light impurities had almost to be eliminated. Most light elements had to be present in not more than a few parts per million. For U^{235} these tolerances could be greatly relaxed. Although it was not yet determined whether the work of final purification would be carried on at Los Alamos or elsewhere, an analytical program was necessary to develop techniques for measuring small amounts of impurity in small samples of material.

1.74 A radio-chemistry program was needed to prepare materials to be used in nuclear experiments and in the development of a neutron initiator for the bomb.

1.75 The metallurgy program included research and development on the metal reduction of uranium and plutonium, the casting and shaping of these metals and compounds such as uranium hydride, as well as various possible tamper materials. Investigation of the physical properties of uranium and plutonium was needed, and a search had to be made for alloys with physical properties superior to those of the unalloyed metals. As its main service function, the metallurgy group would be called upon to prepare materials for physical and ordnance experiments; particularly projectile, target, and tamper materials for the gun program.

1.76 As a somewhat autonomous part of the chemistry program, plans were made for the construction of a deuterium liquefaction plant at Los Alamos. This was to supply liquid deuterium for experimental purposes and for eventual use in the thermonuclear bomb, should its development prove feasible and necessary.

Ordnance Program

1.77 It had been recognized from the beginning that the most difficult of all problems facing the project was to find means for the assembly of several critical masses of material, fast enough to produce a successful high-order

explosion. Subsidiary but still very difficult problems were those of incorporating active material, tamper and assembly mechanism into a practical air-borne bomb. These were the problems of the ordnance division of the project, a division which could haruly be said to exist at the beginning. As a matter of fact, no pre-existing group could have had much success in this work. A new field of engineering was being explored; experience has shown that those successful in this work come from a variety of technical backgrounds, all of which contribute to the field and none of which dominate it: physicists, chemists, electrical and mechanical engineers.

1.78 A corollary feature of the ordnance program has been its simultaneous investigation of alternative methods. The uncertainties of nuclear specification and the possibility that one or another line of investigation might fail, have made such a policy unavoidable. Of the three methods of producing a fission bomb (autocatalysis, the gun, the implosion) that have been discussed, the last two were singled out for early development. Autocatalysis was not eliminated; but it was not subject to development until some scheme was proposed which would give a reasonable efficiency. This did not occur during the course of the project, although autocatalytic methods continued to receive considerable theoretical attention. Of the remaining two methods, the gun appeared the more practical; it used a known method of accelerating large masses to high velocities. The problem of "catching" a projectile in a target and starting a chain reaction in the resulting supercritical mass was obviously a difficult one, but it seemed soluble.

1.79 The method of implosion, on the other hand, was much farther removed from existing practice. The requirement of simultaneous detonation over the surface of a high explosive sphere presented unknown and possibly insoluble difficulties; the behavior of solid matter under the thermodynamical conditions created by an implosion went far beyond current laboratory experience. As even its name implies, the implosion seemed "against nature". Its investigation was

at first undertaken as something to fall back on in case the gun should, contrary to expectation, fail. Credit for the early support and investigation of this method should be given to S. H. Neddermeyer, who at the beginning was almost alone in his belief in the superiority of the method. At a meeting on ordnance problems late in April, Neddermeyer presented the first serious theoretical analysis of the implosion. His arguments showed that the compression of DELETED a solid sphere by detonation of a surrounding high-explosive layer was feasible, and that it would be superior to the gun method both in its higher velocity and shorter path of assembly. Investigation of the method was begun almost immediately. It subsequently received two increases of priority, until at the end of the project it had become the dominant program throughout the laboratory.

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1.80 During the April conferences, the discussion of ordnance served mainly to outline the problems. Considerable attention had been given to the problem of gun design by R. C. Tolman. One member of the reviewing committee at Los Alamos in April was E. L. Rose, an expert in problems of gun design. Rose showed that by the sacrifice of durability, a quite inessential property, the otherwise prohibitive size and weight of a large gun could be reduced to a point where, together with the target, it could be included in a practical bomb. Other elements of the ordnance program discussed were: internal ballistics of the gun, external and terminal ballistics (guiding and seating of the projectile, initiating of the chain reaction), safety, arming and fuzing devices, release and trajectory of the bomb from a plane.

1.81 It is inappropriate to discuss in detail the experimental program of ordnance at this point. Experimental work did not get under way for several months. On the agenda for immediate action were the prior problems of obtaining test guns and high explosives, of building a proving ground, and of employing or training personnel to carry on the research.

Chapter II

THE BRITISH MISSION

2.1 In December 1943 the first representatives of the British atomic bomb project came to Los Alamos. Their arrival marked the climax of a long series of negotiations between the British, Canadian and American Governments seeking to integrate the scientific work being done in all three countries on atomic bomb research (1.2). These first representatives were O. R. Frisch and E. W. Titterton.

2.2 Although Britain's T. A. Project (The Directorate of Tube Alloys) had had a very high priority in 1942, so many of her physicists and so much of her industrial capacity were engaged in other urgent war work that it was impossible to undertake as large a program as the United States had launched. The British organization decided to limit itself to particular phases of the problem, and established research teams in various university and industrial laboratories.

2.3 In the summer of 1942, sufficient progress toward collaboration had been made so that the British reports on the theory of fission and the fission bomb were accessible to Oppenheimer's group in Berkeley, as well as reports of experimental measurements of nuclear constants. At that time the British analysis of the bomb mechanism was somewhat more advanced than in the United States, so that access to these reports was of substantial value. In November 1942 a memorandum (Appendix 7 , No. 5) was written by Oppenheimer to R. E. Peierls describing the theoretical work that had been done at Berkeley and discussing certain points of difference between British and American theoretical work. The incompleteness of collaboration at this time is indicated by the fact that in the memorandum referred to there could be no mention of the deuterium bomb.

2.4 In the fall of 1943 President Roosevelt and Prime Minister Churchill had discussed the possibilities for closer collaboration between the two countries in hastening the production of Atomic Bombs. As a result of their discussions a Combined Policy Committee was set up in Washington. One of this committee's decisions was to move a large number of British scientists to work in American laboratories. Evidence of the genuineness of cooperation that resulted from this sacrifice on Britain's part is the fact that British scientists were given assignments in all parts of the American Project, especially at Los Alamos, the most highly classified section of all. (Appendix 7, No. 6)

2.5 At this time Niels Bohr, the eminent Danish physicist, escaped from Denmark to England, where he was appointed adviser on scientific matters to the British Government. His scientific advice was made available to the United States as well. Bohr and his son Aage came to Los Alamos in December 1943, a short time after Frisch and Titterton. To ensure his personal safety and as a security precaution, Bohr was known as Nicholas Baker and his son as James Baker. Great care was taken to prevent any reference to their real names, even in classified documents. The Bohrs did not become resident members of the Los Alamos Laboratory, but made several extended visits as consultants.

2.6 When Bohr came to the Laboratory he found there a large number of his former students, and his coming had a very healthy influence on research. He came at the right moment. The exigencies of production, the innumerable small problems which confronted the physicists had led them away from some of the fundamental problems of the bomb. The study of the fission process itself, for example, had been neglected, and this obstructed reliable predictions of important phenomena, such as the energy-dependence of the branching ratio between fission and neutron capture (6.44). Here Bohr's interest gave rise to new theoretical and experimental activities which cleared up many questions that were left unanswered before. Some of the most important experiments on the velocity selector were made at his instigation (6.38). His influence was felt

strongly in research on the nuclear properties of tamper materials.

2.7 Bohr's criticism and his concern for new and better methods enlivened the discussion of alternative means of bomb-assembly. Although these discussions showed in the end that the "orthodox" implosion was still the best method, their value was to prove that its choice was, despite its many difficulties, the correct one. Bohr participated very actively in the design of the initiator.

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2.8 Last but not least his influence on the morale of the Laboratory must be mentioned. It went farther than having the great founder of atomic research in the Laboratory, and farther than the stimulus of his fresh suggestions. He saw the administrative troubles of the Laboratory in a better and longer view than many of those enmeshed in them. His influence was to bring about stronger and more consistant cooperation with the army in the pursuit of the common goal. And what can be least overlooked, he gave everybody who was in contact with him some of his understanding of the ultimate significance of the control of atomic energy.

2.9 Another of the Laboratory's most useful British consultants was Sir Geoffrey I. Taylor. Los Alamos was staffed primarily with nuclear physicists, who lacked experience with hydrodynamical investigations. In investigating the hydrodynamics of the implosion and the nuclear explosion, therefore, their work suffered from being too formal and mathematical. Apart from the contributions of the American sonsultant J. von Neumann (7.64), most of the simple intuitive considerations which give true physical understanding came from discussions with Taylor. His most important general contribution was the understanding of the "Taylor instability", which is the generalization that when a light material is pushing a heavy material, the interface between them is unstable (5.27). This principle was important in the theory of jets (16.10), in the interpretation of high-explosive experiments, in the design of the initiator

(15.45), in the design of the implosion bomb, and in the predictions about the nuclear explosion (5.47). To him also was due the stimulus for serious theoretical investigation of the "ball of fire" phenomena (11.28).

2.10 Technical contributions of the resident staff of the British Mission are mentioned in appropriate parts of the text on the same basis as the work of their American colleagues.

2.11 Sir James Chadwick of the Cavendish Laboratory, scientific adviser to the British members of the Combined Policy Committee in Washington, came to Los Alamos early in 1944 to head the British Mission. It was not certain at first whether the British group would work under Chadwick on the problems of his choosing, or whether they would be assigned to existing groups in the laboratory. The latter arrangement was adopted, and eventually British scientists worked in nearly all of the Laboratory Divisions. Seven were experimental nuclear physicists, two were electronics experts, five were theoretical physicists, and five were experts in the properties and effects of explosives.

2.12 Lord Cherwell, Churchill's personal adviser on scientific matters, visited Los Alamos in October 1944.

2.13 Chadwick stayed in Los Alamos only a few months. His successor as head of the Mission was Peierls.

2.14 Apart from the consultants already mentioned, the British Mission staff consisted of the following: E. Bretscher, B. Davison, A. F. French, O. R. Frisch, K. Fuchs, J. Hughes, D. J. Littler, C. Mark*, W. G. Marley,

* Although several members of the Mission came to Los Alamos via the Canadian and United Kingdom Laboratory in Montreal, all were attached to the British staff except C. Mark, who remained in the employ of the Canadian Government.

D. G. Marshall, P. B. Moon, W. F. Moon (secretary), R. E. Peierls, W. J. Penney, G. Placzek, M. J. Poole, J. Rotblat, H. Sheard, T. H. R. Skyrme, E. W. Titterton, J. L. Tuck.

Chapter V

THEORETICAL DIVISION

Organization

5.1 The broad purpose for which the Theoretical Division was formed as had been said (1.55-7) was to develop nuclear and hydro-dynamical criteria relating to the design of the atomic bomb, and to predict the detailed performance of the weapon designed. At the beginning the bulk of the Division's effort, accordingly, was devoted to the investigation of two closely related key problems: the calculation of the critical mass and the nuclear efficiency.

5.2 The first organization of the division centered around these problems. With the rise of the implosion to prominence the organization of the Division, under H. A. Bethe as Division Leader, was formalized as follows (beginning March 1944):

T-1.	Hydrodynamics of Implosion, Super	E. Teller
T-2.	Diffusion Theory, IBM Calculations, Experiments	R. Serber
T-3.	Experiments, Efficiency Calculations, Radiation Hydrodynamics	V.F. Weisskopf
T-4.	Diffusion problems	R.P. Feynman
T-5.	Computations	D.A. Flanders

5.3 During June, 1944, R. Peierls took charge of the Implosion Group in place of E. Teller who formed an independent group outside the Theoretical Division (13.1). This group acquired full responsibility for implosion IBM Calculations. During July 1944 Group O-5 (F-8) joined the Theoretical Division on a part time basis, its work in the Ordnance Division being largely completed (14.1).

Diffusion problems.

5.4 One of the tasks of the theoretical program at the beginning of the Laboratory was the development of means for predicting accurately the

were of three velocities (fission energies, intermediate and thermal). A number of other methods mentioned above were also tried out on this problem, primarily with the purpose of examining the variation among them and as a test of their power when applied to a new problem. The finally predicted value of the critical mass for the water boiler was almost exactly correct; a pleasing, though rather fortuitous result in view of subsequent revisions of the cross-sections involved.

5.16 A number of other problems affecting the operation of the water boiler were examined theoretically; cooling and shielding, effects of temperature changes on the degree of criticality, effect of sudden changes in the position of the control rods, etc. After the boiler was put in operation, the theorists were of service in connection with experiments, such as the interpretation of fluctuations in its operation. This work was essentially completed by the beginning of 1944. Most groups participated in one or another type of water boiler calculation, but the main work was that of R. F. Christy in Group T-1.

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The gun.

5.17 Critical mass calculations for the gun assembly were complicated primarily by the odd shape of the assembly. DELETED DELETED DELETED The critical mass problem for the gun was not only that of estimating the number of critical masses in the completed assembly, but also of estimating the amount of active material that could safely be disposed in the two parts before assembly. It was also necessary to know how the system went from its initial subcritical to its final supercritical position, in order to be able to calculate the probability of predetonation. The early rough specifications for the gun had been based on critical mass estimates from

differential diffusion theory.

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By February 1944, there was pressure from the Ordnance Division to obtain more reliable specifications, and at this time sufficiently accurate calculations had been made so that, for the U^{235} gun, Group T-2 specified a DELETED gun. The specification of the DELETED for the Pu^{239} assembly was reached a short time later. The same group was able to give essentially complete specifications by the summer of 1944 for both gun assemblies, fortunately after cross-section measurements by the Detector Group had resulted in slightly lower average values for U^{235} than those used in earlier calculations.

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The Implosion

5.18 The history of theoretical implosion studies lies mostly outside the Theoretical Division until the Fall of 1943. The idea of something like an implosion, as an alternative to gun assembly, had entered several heads before the beginning of Los Alamos. Its first history at Los Alamos belongs mainly to the Ordnance Division, where the initial calculations of attainable assembly velocities were made.

5.19 The Theoretical Division entered the picture when the fast implosion was proposed by von Neumann, and its potentialities as a weapon qualitatively superior to the gun were appreciated. The general story of this development is told in Chapters 7, 15 and 16. Here the emphasis will be upon the theoretical problems that were involved. Implosion studies were the responsibility of Group T-1, with the assistance of other groups, particularly T-2.

5.20 The first problem attacked was that of the time of assembly when (as proposed by von Neumann) large amounts of explosive were used. In this case, the energy required for the work of plastic deformation was small compared

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to the total energy of the explosive, so that to a first approximation the kinetic energy of the mass moving inward could be assumed to be conserved.

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The numerical solution of the partial differential equation describing the implosion was too difficult for hand calculation with the computing staff available at Los Alamos, when a realistic equation of state was employed. As a result the first effort made was to find simpler approximate equations of state. The first method was based on a multiphase model, in which the state of the imploding material was assumed to change discontinuously. A considerable amount of effort was put into the multiphase model, but the results proved very difficult to interpret.

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These machines arrived in the first part of April, 1944, and in the meantime preparations had been under way for numerical integration of the hydrodynamical equation by means of them. Preliminary calculations had to be made to determine the initial conditions at which to start the IBM calculations. It was necessary to derive the equation of state of uranium at high pressures, a calculation based on the Thomas-Fermi model of the atom. Results at low pressures were obtained from experimental data of P. W. Bridgman, and the intermediate region determined by interpolation.

5.24 The first results of IBM calculation of the implosion were extremely satisfactory. As a result the unrealistic multiphase implosion model was dropped.

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5.28 From these two developments there started a trend of thought that radically altered the whole implosion program. From the IBM results the behavior of the symmetric implosion was soon rather completely understood.

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Efficiency.

5.32 The calculation of efficiency was perhaps the most complex problem that the Theoretical Division had to face. The theory of efficiency had to follow the neutron chain-reaction and neutron distribution in the bomb, in a medium of fissionable and tamper material that was itself being rapidly transformed by the reaction in both its nuclear and dynamic properties. Every factor involved in the critical mass calculations was involved here, but in a dynamical context which made dubious some of the simplifying assumptions underlying those calculations.

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Calculations were so insecure that they were never incorporated into the final efficiency calculations for the bombs produced in 1945. But an understanding of the theory in qualitative terms was an important factor in the final decisions on tamper specifications.

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The Super.

5.50 The deuterium bomb or "Super" project was relatively divorced from the main work of the Laboratory. As a development secondary to that of the fission bomb, its importance was nevertheless such that it was carried on throughout the course of the Laboratory. From its first conception, before

Los Alamos, this work was under the direction of Teller. In the last period of the Laboratory Teller was joined by Fermi. By coincidence the first idea of such a bomb, at least in relation to the Los Alamos program, had been evolved in a lunchtime discussion between Fermi and Teller early in 1942.

5.51 A fundamental understanding of the fast thermonuclear reaction had been reached by the beginning of Los Alamos. In the first rough calculations Teller had ignored the effect of radiation, which is to drain off energy at a rate that increases rapidly with temperature. These early rough calculations indicated that the reaction would take place if ignited by the explosion of a fission bomb as "detonator". They also indicated, in fact, that the reaction would go too well, and that the light elements in the Earth's crust would be ignited.

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5.54 These matters were well enough understood in the Summer of 1942 to make it apparent that a Super could, in principle, be made. At the Berkeley summer conference in 1942, Teller presented his analysis of the mechanism and argued that such a bomb was feasible. A good part of the discussion at this conference was devoted to the examination of Teller's proposals.

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5.56 One further suggestion of great eventual importance was made by Konopinski. This was to lower the ignition temperature of deuterium by the admixture of artificially produced tritium (hydrogen ^{3}). The apparently very much greater reactivity of tritium led him to this proposal. It was not immediately followed up because of the obvious difficulty of manufacturing tritium and the hopefulness of igniting pure deuterium. Eventually, as it will

develop, new difficulties of ignition were to be uncovered so that the introduction of artificial tritium began to appear necessary.

5.57 One further topic was discussed at the Berkeley conference, the effect of secondary nuclear reactions. Products of the deuterium-deuterium (D-D) reaction were, with about equal probabilities, a helium^3 nucleus plus a neutron, or a tritium nucleus and a proton. It was pointed out by Bethe that the reaction of deuterium with tritium, even though secondary, was of considerable importance. The T-D reaction releases nearly five times as much energy as the D-D reaction; the reaction cross-section was moreover likely to be considerably larger.

5.58 The consequences of the Berkeley discussions of the Super were that its investigation was continued, that measurements of the D-D and T-D cross-sections were undertaken, and that, when the Los Alamos Laboratory was being planned, a research program on the Super was included.

5.59 After the conference and before Los Alamos the measurement of the D-D cross-section was undertaken by Manley's group at Chicago, and that of the T-D cross-section was undertaken by Holloway's group at Purdue.

5.60 At Los Alamos no systematic theoretical work on the Super was undertaken until the fall of 1943. A cryogenic Laboratory was started by the group under E. A. Long, with the object of building a deuterium liquefaction plant. A considerable amount of work on the properties of liquid deuterium was carried out by Prof. H. L. Johnston under subcontract at Ohio State University (8.96 - 8.99).

5.61 In September, Teller proposed that there be more intensive investigation of the Super. Experimental cross-sections had been revised upward, so that the bomb would be feasible at lower temperatures. In addition there was some slight evidence that the known German interest in deuterium might

be directed toward production of a similar bomb. Work was resumed at this time, but not with high intensity. Teller and his group were largely occupied with other and more urgent problems.

5.62 In the Winter of 1943-44 an important new theoretical problem was uncovered.

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5.63 The recognition of this new dissipative mechanism became the occasion for a revaluation of the Super program. This program was discussed at length in a meeting of the Governing Board on February 24, 1944, at which Teller reported on the current state of knowledge (Appendix 7, No. 20). Detailed quantitative investigation of DELETED DELETED was needed, but would lengthen the time-scale of the program. In case these

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investigations should show that the difficulty of igniting deuterium was too great, there was one remaining alternative, which was to return to the proposal of Konopinski to lower the ignition temperature by admixture of tritium. A small percentage of tritium would bring the ignition temperature down from the neighborhood of twenty kilovolts to around five. DELETED

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5.64 The practicability of using a tritium-deuterium DELETED DOE b(3) limited by the very great difficulty of obtaining tritium. It could be produced from the reaction of neutrons with lithium^{6}, yielding tritium and helium^{4}. The very small sample of tritium that had been used in cross-section measurements at Purdue had been produced by cyclotron bombardment. Larger scale production would be possible in such a pile as the Hanford pile, but could utilize only the small percentage of excess neutrons not needed to keep the pile in production.

5.65 Both because of the theoretical problems still to be solved and because of the possibility that the Super would have to be made with tritium, it appeared that the development would require much longer than originally anticipated. Even though this was the case, it was decided that work on the feasibility of so portentous a weapon should be continued in every way possible that did not interfere with the main program. Tolman, who was present at this meeting as General Groves's adviser, affirmed that although the Super might not be needed as a weapon for the war, the Laboratory had a long-range obligation to carry on this investigation.

5.66 Although no final decision was made at the meeting referred to, it in fact defined subsequent policy. In Teller's group further theoretical work was carried on, which confirmed the difficulty of igniting pure deuterium.

In May 1944 Dr. Oppenheimer discussed the matter of tritium production with General Groves and C. H. Greenewalt of the du Pont Company. It was there decided that experimental tritium production would be undertaken, using surplus neutrons in the Clinton pile.

Damage.

5.67 The detailed investigation of damage and other effects of nuclear explosion was not pursued very far in the period under review. Some results, going beyond the rough estimates reported in 1.52 were, however, obtained in the summer and fall of 1943. There was further investigation of the shock wave in air produced by the explosion, of the optimum height for the explosion, of the effects of diffraction by obstacles such as buildings and of refraction caused by temperature variation. There was some calculation of the energy that might be lost through the evaporation of fog particles in the air. Estimates were made of the size of the "ball of fire" after the explosion, and the time of its ascent into the stratosphere. The theory of shallow and deep underwater explosions was investigated, and led to the suggestion of model experiments.

5.68 One important question was cleared up at this time, which was the nature of the dependence of damage upon the characteristics of a shock wave in air. For small explosions damage is roughly proportional to the impulse, which is pressure integrated over the duration of the pulse (i.e., the average pressure of the pulse times its duration). Investigation made clear the fact (not unknown elsewhere) that existing blockbusters are near the limit of size at which further increase of the duration of the pulse has any advantageous effect on the damage. For large explosions such as those contemplated, damage depended only on the peak pressure. This was important because the peak pressure depended on the cube root of the energy, whereas the impulse depended on its

two-thirds power. Large bombs are relatively less effective (from the point of view of purely physical damage) than small ones for this reason. Calculations made at the time showed that for bombs of the order of ten thousand tons of TNT, the peak pressure would fall below the level of "C" damage at a radius of 3.5 kilometers.

5.69 Another important point was clarified at this time, connected with the optimum height of detonation. It had been known that the reflection of shock-waves by solid obstacles increases the pressure of the shock wave. It was shown at this time, however, that this effect was much greater for oblique incidence than had been believed from elementary considerations; in fact oblique incidence up to an angle of sixty or seventy degrees from the vertical gives a greater pressure increase than normal incidence. Hence it was concluded that a considerable improvement in the damage radius could be obtained by detonation at an altitude not small compared to the expected radius of damage--in fact of one or two kilometers.

Experiments

5.70 Some of the more important cooperative work as between the Theoretical Division and the other divisions of the Laboratory has already been mentioned; for example the interpretations of scattering data, and calculations of the water boiler and hydride critical masses, and the calculations made of the hydrodynamical characteristics of the implosion. There was however a more extensive cooperation than these isolated instances would suggest. Work done ranged from cases such as these in which the theorists played a large and semi-independent role, to ordinary service calculations, particularly the analysis of experimental data. For this latter work and for consultation in the design of experiments, every experimental group had theorists assigned to it. Calculations of a fairly extensive sort were necessary in all experiments in

which "integral" considerations were involved, i.e. in which the results depended upon nuclear constants in a complex statistical way. For it then became necessary to relate the measured quantities with these constants by theory, and to use this theory first to decide whether a given experimental design would yield sufficient accuracy to justify its execution, and second to interpret the data obtained. The theorists played this part in most of the experimental determinations of nuclear quantities described in Chapters VI and XII.

5.71 One rather conspicuous example of theoretical influence on the design of experiments was the "Feynman experiment", an experiment which was never performed but whose principle was embodied in several experiments. This was simply the proposal to assemble near-critical or even supercritical amounts of material safely by putting a strong neutron absorber (the B^{10} boron isotope) uniformly into the core and tamper. For an absorber with an absorption cross section inversely proportional to the velocity of the neutrons absorbed, it could be shown that the effect was to decrease the multiplication rate in the system by an amount which was directly proportional to the concentration of absorber. Thus an amount of material which would be supercritical could be made subcritical by the addition of boron; from a measurement of the rate at which the neutron <u>died out</u> in this system, the rate could be simply calculated at which they would <u>increase</u> if the boron were absent.

5.72 The theoretical groups assisted the Detector Group of the Experimental Physics Division and others in the theoretical analysis of the efficiency and other characteristics of detectors and counters.

5.73 Aside from its main work in connection with the gun and implosion assemblies, discussed above, the Theoretical Division made numerous

other analyses and calculations relative to the experimental work of the Ordnance Division. In preparation for the RaLa experiments for example, Group T-3 analyzed the attenuation of gamma-rays in a homogeneous metal sphere surrounding the source, and calculated the way in which this attenuation would be increased with compression during the course of an implosion of the metal sphere. As another example, the theory of the magnetic method of implosion study was investigated in the Theoretical Division in collaboration with the experimentalists.

5.74 Mention should be made here of safety calculations made by Group T-1 and later by Group F-1 for the Y-12 and K-25 plants. The Group Leader, E. Teller, was appointed as consultant for the Manhattan District as a whole on the dangers of possible supercritical amounts of material being collected together in the plants producing separated U^{235}.

5.75 During the period described the computations group, T-5, carried out innumerable calculations for other groups in the Division, and related investigations in the mathematical theory of computation. Like other service groups, its scanty mention is no indication of the importance of its work, without which the work of the division would have been in fact impossible.

design, the choice of a tamper had to be made as soon as possible. The notion prevailed for some time that inelastic scattering (i.e., scattering, in which the neutrons, although not captured by the tamper nuclei, lose part of their energy to them by excitation) would play an unimportant role, since it would probably reduce neutrons to a very low energy where they would not contribute materially to the explosive chain reaction. Very little was known, moreover, about the variation of scattering with neutron energy. It was thought, at the time, that the most important part of the fission spectrum lay at high energies, near 2 Mev. It was felt that to a first approximation the usefulness of a tamper would be determined by the number of neutrons reflected backward to the core. It was therefore decided that the most rapid collection of pertinent information could be made by comparing the back scattering of trial tamper materials for D(d,n) neutrons from the Cockcroft-Walton. This could be done using either a non-directional detector with a paraffin "shadow cone" to reduce direct beam, or with a directional detector. The shadow cone method greatly reduced the range of scattering angle measurable. It was thought that a directional detector could give an average over the angles from 120° to 180° in the geometry possible.

6.50 The D-D Group undertook these measurements by both methods in August 1943. The first directional detector was a spherical ionization chamber with a large directionality factor. The first scatterers measured were discs 1 inch thick and 10 inches in diameter of lead, iron, gold and platinum. The latter two, vulgar wonders in an atomic bomb laboratory, brought a great stream of visitors from other groups. Lead showed up best per unit weight, but because of its relatively low density was not much better than gold or platinum.

6.51 Although the geometry used for back-scattering covered the angles 120° to 180°, it was discovered - as theory caught up with experiment - that a very small range of angle near 137° was weighted predominantly. Hence if back scattering were not uniform, the data obtained could be quite misleading. Several councils

of war about this state of affairs resulted in an extension of the measurements.

6.52 This incident was of some importance in the growth of the Laboratory. An essential part of the design of such an experiment as this is sufficient preliminary analysis and calculation to show that from a given experimental arrangement the data sought can actually be got. For efficiency most of the elaborate calculations of this sort are delegated to members of the Theoretical Division because of their special skill. In this case the liaison between the latter and the D-D Group had been inadequate and a need for closer liaison was recognized.

6.53 By the end of October 1943 back-scattering measurements had been completed for a large list of substances, and a number of instrumental improvements had been made. After the first survey, the list of possible tamper materials was restricted to tungsten, carbon, uranium, beryllium oxide, and lead. At about this time, also, measurements of the fission spectrum indicated that the important energy range was nearer 1 Mev than 2 Mev. Results of the first experiments indicated, moreover, that earlier ideas about inelastic scattering were incorrect, and that inelastically scattered neutrons could play an appreciable role in the functioning of a tamper. Recognition of their possible importance was made easier, also, by the current concern of the Laboratory with the uranium hydride bomb. The same increase in cross section with decreasing energy that made this bomb seem feasible also suggested that neutrons slowed by inelastic scattering might still make a considerable contribution to an explosive chain reaction.

6.54 For these reasons preparations were made for the study of scattering as a function of energy and scattering angle, taking account of inelastically scattered neutrons. This work was done cooperatively by the D-D and Electrostatic Generator Groups, beginning in November 1943. Back-scattering data were obtained at 1.5 Mev and 0.6 Mev, as well as 3 Mev. In addition to

overall back-scattering measurements, an experiment was performed to give specific information on the degraded neutrons as a function of primary neutron energy for the elements still in the running as scatterers.

6.55 Materials studied in these experiments were carbon, lead, uranium, beryllium oxide and tungsten. These are listed in the order in which they appeared promising. DELETED DELETED DELETED During May, June and July 1944, this series of experiments had been extended to uranium nitride, lead dioxide, cobalt, manganese, nickel and tantalum at several energies. DELETED DELETED DELETED

6.56 One further scattering experiment was begun in this period, an integral experiment which would attempt to obtain information about the hydride bomb. The D-D source was to be surrounded by a modifying sphere mocking the hydride core as nearly as possible, integral tamper properties would be investigated around this core as well as neutron distribution in tamper and core. One instrumental development that occurred in this connection was a new fission detector. This was a spiral ionization chamber with a spiral of depleted U^{238} so wound as to give a large surface area in a small volume. This counter operated at efficiencies as high as 85 per cent.

The Water Boiler

6.57 The first chain reacting unit built at Los Alamos was the water boiler, a low-power pile fueled by uranium enriched in U^{235}. It was the first pile built with enriched material, the so-called alpha stage material containing about 14 per cent U^{235}. The necessary slowing down or moderation of fission neutrons is provided in this system by the hydrogen in ordinary water: the active mixture is a solution of uranyl sulfate in water solution. The tamper chosen was beryllium oxide.

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The necessary presence of Pu^{240} in the Hanford plutonium (4.52) decreased the minimum time of assembly of this material far below what was possible by gun-assembly methods.

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Projectile, Target and Initiator Design

7.31 Although the development of designs of projectiles, targets and initiators for the gun assembly should be capable of moving more rapidly than the development of the gun itself, the uncertainties surrounding the problem were relatively more serious. Not only were the physical properties of plutonium entirely unknown, but the whole problem of producing an assembly of projectile and target that would start the chain reaction under favorable conditions, i.e. at the right time and in a compact geometry, was entirely new. Accumulated experience on armor penetration greatly discouraged early suggestions that the projectile be stopped by the target. The conception of a gun assembly, as of April 1943, was rather one in which the projectile passed through the target freely

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7.32 Before any work was started on these developments, the plan was complicated by the further uncertainty in the amount of active material that could be safely disposed in the projectile alone, or in the target. This was particularly important in the case of the hypothetical uranium hydride gun; for here the critical mass would be small, while for effectiveness a large number of critical masses would

have to be assembled. [redacted]

DOE b(3) [redacted] Although planned primarily for the hydride gun, the critical mass calculations for odd metal shapes were not at the time accurate enough to rule out a possible need for such methods in the metal gun model. The development of these mechanisms was a difficult undertaking which remained uppermost in the efforts of the groups concerned until February 1944, by which time the hydride gun had been abandoned [redacted]

7.33 The design development of projectiles, targets [redacted] was centered in the Projectile and Target Group. [redacted]

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7.64 Interest in the implosion thus remained secondary to that in the gun assembly. There was some consideration of the possibility of using larger amounts of explosive to increase the velocity. But the impossibility of recovery and the currently incomplete instrumentation kept such things in the "idea" stage for several months. The decisive change in this picture of the implosion occurred with the visit of J. von Neumann in the fall of 1943. Von Neumann had had previous experience with the use of shaped charges for armor pentration. Von Neumann and Parsons first advocated a shaped charge assembly, by which active material in the slug following the jet would be converted from a hollow cone shape to a spherical shape having a lower critical mass value. He was soon persuaded, however, that focussing effects similar to those which are responsible for the high velocity of Monroe jets would operate within an imploding DELETED sphere. DELETED

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7.65 It cannot be said that these radical proposals were unanticipated in the Laboratory. Certainly their qualitative peculiarities had not been grasped, or urged as a decisive advantage. Predominantly until this time the implosion had been conceived as a means of squeezing solid matter into a solid sphere, with quantitative advantages over the gun, to be weighed against its much greater uncertainty of success.

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7.66 Once discussion was started on this plane, a further fact of great ultimate importance became apparent. In conversations between von Neumann and Teller the latter pointed out that

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7.68 Another major consequence of the new emphasis was the planning and eventual realization of an adequate high explosives production plant and research program. For this development as well as for general assistance to the research in implosion dynamics, the consulting services of G. B. Kistiakowsky were acquired by the Laboratory in the fall of 1943. In February 1944, Kistiakowsky joined the staff as Capt. Parsons' deputy for the implosion. In April he assumed full direction of the rapidly increasing administrative problems of this work.

7.69 The period preceding February 1944 was spent in vigorous development of experimental techniques. The art of recovery from weak charges was the most rapidly exploited technique, since it required no elaborate instrumentation. Procurement of the spheres required was beyond the capacity of the laboratory shops; outside procurement was arranged through the offices at Detroit and Los Angeles. Although the test conditions were admittedly far from those in a fast

implosion, the recovery technique proved useful in the interpretation of the process and in revealing the importance of and possible difficulties in obtaining symmetry. By February evidence had been obtained of possible trouble from the interaction of detonation waves and from the spread of detonation times in multipoint detonation. These were not yet, to be sure, thought of as basic defects lying outside the range of existing experimental techniques to correct.

7.70 The other techniques that were inaugurated in this period were chiefly in a stage of being perfected to the point where they would be of quantitative usefulness to the investigation. The difficulties lay principally in the necessity for recording events inside an explosive and for timing these events within an uncertainty of the order of one microsecond. In November a program for photographing the interior of imploding cylinders by high explosive flash light, (a method developed at Bruceton) was started. Some qualitative results were soon obtained but refinement of the method and elimination of secondary blast effects required until spring to achieve. Practically the same history applies to the flash X-ray method of studying small spheres. The principal problem presented by this method was the precision of time correlation between the implosion and the X-ray discharge. This problem was solved, in cooperation with the Ordnance Instrumentation Group, by extensive modification of the commercial X-ray machines. The Instrumentation Group had also designed and had constructed rotating prism cameras making use of ultra-centrifuge techniques. These were adapted to proving ground use for taking rapidly repeated photographs of cylindrical implosions in December and January, but were never used effectively for their intended purpose. Much later they were used successfully in lens investigations (16.46). Also in December, field preparations were started for taking electronic records of objects imploded in a magnetic field. The first shot of this type, the "magnetic method", was fired January 4, 1944, and the results were encouraging. The "magnetic method" was designed to take advantage of the fact that the motion

of metal in a magnetic field alters the field. Thus the inward motion of an imploding metal [redacted] would induce a current in a surrounding coil, and the proper interpretation of this current would give information on the velocity and other characteristics of the implosion. Considerable perfection of the electronic records was needed, however, and this held up final proof of the method until spring.

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7.71 Quantitative data from the X-ray, high explosive flash and rotating prism camera techniques showed the usefulness of these methods for determining velocities and symmetry at small scale, but also indicated a necessity for controlled quality of high explosive castings and boostering systems, as well as improved simultaneity of detonation. Programs were instituted for the improvement of these services; this involved the production of castings of uniform density and composition by the institution of quality control, including X-ray examination and density measurement of charges. In view of the impending large scale production of heavy charges, development work was also undertaken on methods of casting and examining such charges for controlled quality.

7.72 Whereas the original Anchor Ranch Range had been designed to accommodate both the gun and implosion programs, the expansion of the latter soon crowded the Anchor facilities. In particular the casting and detonation of large charges required a large casting plant and several widely separated test sites. The largest of these units, the casting plant, was begun in the winter of 1943. It included an office building, steam plant, a casting house, facilities for trimming and shaping high explosive castings and magazines for storage of high explosive and finished castings.

7.73 This S site (sawmill site) was one of the most difficult undertakings of the Laboratory from an administrative point of view. To find men with experience in high explosive casting work, or even with general experience in handling explosives, proved for the most part impossible. Supervisory personnel were equally difficult to obtain. Almost the only available channel was the army;

the 3 Site Group was staffed almost entirely by men in the SED. Among these a few had appropriate industrial backgrounds, a larger number were young soldiers with some scientific training, usually in chemistry, and the rest were relatively unskilled hands. Originally scheduled for completion in February and full operation in April 1944, steady operation on a reasonable scale did not actually get under way until August. Because of increasing demand and the unavoidable lag in 3 site expansion, it was early in 1945 before the small original Anchor casting room was fully replaced as a source of supply for experimental charges.

7.74 The first of the new experimental methods to be successfully adapted to work at larger scale was the high explosive flash technique, which was used not only with cylinders but also with hemispheres. In the early months of 1944 attention was being given to extending flash X-ray methods to larger scale and using a grid of small ion chambers instead of photographic recording. This work was, however, only begun in the fall (15.19ff). The "RaLa" method, that of including a strong source of gamma radiation in the imploding sphere and measuring the transmitted intensity as a function of time, was being discussed, and active development was gotten underway, including electronic instrumentation and preparation for handling the highly radioactive radio-lanthanum (RaLa) to be used.

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The possible use of the betatron to produce penetrating radiation for work with large spheres was discussed at this time; but it was not decided to use the technique until the beginning of the second period (15.26 ff). Lastly, the possibility of making a full-scale, active test in a closed vessel was also being considered and model tests were started and procurement possibilities investigated. Use of such a containing vessel would permit recovery of active material in case of a

complete fizzle. This later grew into the "Jumbo" program which, together with other engineering problems, was centralized under the Ordnance Instrumentation Group and later under a special group devoted to this program (16.53 ff).

7.75 Preparations for an implosion test with active material were begun in March 1944. The main problems were (a) the choice of a test site, (b) the investigation of methods to permit recovery of active material in case of failure of the nuclear explosion, and (c) the design of instrumentation to measure blast effects and nuclear effects of a successful explosion. Discussion of the third topic is referred to Chapter XVIII. Sites considered were in New Mexico, Colorado, Arizona, Utah and California, as well as several island sites off the coasts of California and Texas. In making the choice the advantage of nearness to Los Alamos had to be weighed against possible biological effects even in sparsely populated areas of the Southwest. During the period before August 1944 a good deal of exploration was by map, automobile and plane, and still more was planned. Investigation was begun, finally, of several aspects of the recovery problem. Recovery from a large containing vessel strong enough to withstand the shock of the high explosive alone was the principal means considered. Also investigated was the possibility of setting off the bomb inside a large sand pile which would prevent dispersal and permit recovery of active material in case of failure. Other methods were investigated, but during the period in question the main problem was that of designing "Jumbo", the containing vessel.

7.76 The main activities of the spring and early summer months may be summarized as follows: (1) the preliminary development of new methods, such as RaLa, the magnetic method, the counter X-ray method, which should be useful with larger scale implosions; (2) increasing production and quality control of cast explosives and detonation trains; (3) increased investigation of questions of simultaneity in detonation, including the preliminary investigation of electrical detonation systems; and (4) the exploitation of techniques established during the

winter for studying the implosion. Implosion studies only reached the stage of giving regular and reliable results during the summer of 1944: being concerned with end results, they were the object of great attention from the rest of the Laboratory and particularly from the Theoretical Division. In fact this early work laid the foundation of a new branch of dynamics, the physics of implosion. It had been firmly established that the earlier results on implosion velocities were essentially correct, and considerably lower than theory predicted for normal impact by a detonation wave. The dynamics of confluent materials had also been thoroughly investigated.

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DELETED e Laboratory faced the fact that the gun method could not be used for the assembly of plutonium. Hence at that time there was not a single experimental

result that gave good reason to believe that a plutonium bomb could be made at all. There was, however, a large investment in plants and proving grounds and a wide background of experience in improving explosives and timing, which made it possible to launch an even more ambitious investigation of the implosion. The new development was to be centered on the possible use of explosive "lenses" which could be designed to convert a multiple point detonation into a converging spherical detonation wave and thus eliminate the troublesome interaction lines. Preliminary studies of such systems had been made in England and at Bruceton and the work of adapting them to the implosion problem became the principal objective of the implosion groups. The requirement for experimental lens-mold design was the most difficult initial step and this occupied some months. Meanwhile, the effort to eliminate the interaction jets from non-lens implosion continued

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7.79 The decision to go into the study and use of explosive lenses entailed expansion of research DELETED DELETED DELETED Furthermore, the eventual production of these special explosive systems had to be provided for. To be prepared for the use of the first quantities of plutonium all this had to be accomplished well within a year. The major portion of the Laboratory was accordingly reorganized so as to concentrate its manpower

and facilities on the implosion problem. Division X was formed, under Kistiakowsky, for the purpose of experimentation with explosive systems and their method of fabrication and for setting up an adequate production system for all special charges (9.1 ff, Ch. XVI). Also under Division X were put the more or less established methods of implosion investigation, such as the small scale X-ray and the high explosive flash methods. The development of new or as yet unproved techniques for the investigation of implosion dynamics, and the responsibility for design development of the active core of the implosion was made the objective of G Division under Bacher (9.1 ff, Ch XV). The urgency of the directives of these divisions is readily appreciated when it is considered that there was no approved design of either explosive or mechanical systems at the time of the reorganization, August 14, 1944.

Delivery

7.80 The work of the Delivery Group covered everything from the completed bomb (gun or implosion model) to its final use as a practical air-borne military weapon. In the nature of the case there was considerable overlapping between its responsibilities and those of the groups engaged in final bomb-design; particularly with the Fuse Development Group (7.42 ff), the Engineering Group (7.49 ff) and other groups responsible for bomb design. Even in these cases however, it was the especial responsibility of the Delivery Group to see that cooperating groups functioned smoothly together as a team with an eye to their eventual collaboration in combat delivery. In addition to this responsibility and to its own proper functions in design and procurement, the Delivery Group was responsible for liaison with Air Forces activities including the choice and modification of aircraft and the supervision of field tests with dummy bombs. In the second part of this history it will be seen that the activities of the Delivery Group (then expanded into what was called Project A) were extended to include the planning and establishment of the advance base where the bombs were assembled, [illegible] of the bombs, and the tactical training of

the bombs in flight (Chapter XIX).

7.81 The first activities of the delivery program began in June 1943 when N. F. Ramsey (then still working with the Air Forces) undertook to investigate available planes with respect to their bomb carrying capacity. DOE b(3) DELETED DELETED DELETED The only plane which would fit this requirement was the B-29, which even so could carry the bomb only by joining the bomb bays. The possibility of wing-carriage by other planes had been considered and rejected. At this time it appeared that there might be considerable difficulty in obtaining a test B-29. Another plane capable of carrying the bomb was the British Lancaster, and some investigation was made of the possibility of using this plane. In terms of standardization of maintenance, however, this plane would have been difficult to operate from American bases; it was therefore decided that the B-29 would have to be used.

7.82 Preliminary ballistic tests were made in August 1943 at the Naval Proving Ground at Dahlgren, ostensibly for the Air Corps. DOE b(3) DELETED DELETED DELETED These models consisted of a long 14" pipe welded into the middle of a split standard 500 pound bomb. They showed, on testing, extremely bad flight characteristics. In subsequent months further tests of scale models were made at Dahlgren, and models developed which had much better flight characteristics. During this period preliminary models of a proximity fuse developed at the University of Michigan (7.45) were also tested.

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7.83 On the occasion of Ramsey's first visit to Los Alamos in September 1943, the [redacted] implosion (7.64) was just being urged by von Neumann. From this model a preliminary estimate was made of a nine thousand pound bomb with a diameter of 59 inches. On the basis of these estimates the Bureau of Standards bomb group was asked, through the Bureau of Ordnance, to have wind-tunnel tests

made to determine the proper fairing and stabilizing fins for such a bomb.

7.84 In the Fall of 1943 plans for full scale tests were gotten under way. For the purpose of B-29 modification, two external shapes and weights were selected as representative of current plans at Los Alamos. These were respectively 204 and 111 inches long, and 23 and 59 inches in diameter, the "Thin Man" (gun) and "Fat Man" (implosion). In November 1943 Ramsey and General Groves met with Colonel R. C. Wilson of the Army Air Forces, and plans were discussed for the first modified B-29. In December the first full scale models were ordered through the Detroit Office, and Ramsey and Capt. Parsons visited the Muroc Airbase to make the necessary test station plans.

7.85 Tests were begun at Muroc early in March 1944. The purpose of these tests was to determine the suitability of the fusing equipment, the stability and ballistic characteristics of the bombs, and the functioning of the aircraft and bomb release mechanism. The flight characteristics of the Thin Man model proved stable, while those of the Fat Man were under damped which caused a violent yaw and rotation. The fuses tested, the Michigan proximity fuses (7.45), failed almost completely. The release mechanism proved inadequate for the Thin Man. Four models "hung up" with delays of several seconds. The last model tested released itself prematurely, while the plane was still climbing for altitude. This bomb dropped on to the bomb bay doors, which had to be opened to release the bomb and were seriously damaged. This accident ended the tests pending repair of the plane and revision of the bomb release mechanism.

7.86 Tests at Muroc were not resumed until June, pending plane repair and modification. The intervening time at Los Alamos was devoted to a number of activities: the analysis of the first Muroc data, the planning of a functional mock-up of the plane and bomb-suspension for handling, loading, shaking and cold tests, and construction of a site (V Site) for this work; investigation of the need and possibility of heating equipment for the B-29 bomb bay.

7.87 In addition effort was devoted to the design and procurement of 23/59 scale Fat Man models for possible B-24 flight tests. Negotiations were started to obtain the use of the high-velocity Moffett Wind Tunnel for bomb ballistic experiments on the Fat Man. Although stable and statistically reliable Fat Man models were subsequently designed without this, only ballistic experiments under controlled conditions would have yielded definite information on the safety factors involved in these models. The necessary arrangements for this testing program proved difficult to make, and it was in the end deemed unnecessary.

7.88 During this period also two new bomb models were designed. DOE b(3)

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The length of this model was so reduced that it could be carried in a single B-29 bomb bay. When in midsummer the plutonium gun assembly was abandoned, it became unnecessary to join the bomb bays of the plane. The second model was the "1222" Fat Man model. This consisted of twelve petagonal sections of dural bolted together to form a sphere, and surrounded by an armor steel shell of icosahedral structure, with stabilizing shell attached. Mechanical assembly of this device required the insertion of some 1500 bolts.

7.89 The chief contribution of the Muroc tests in June was that although the Fat Man model tested was still unsatisfactory in its flight characteristics, field modifications, resulting from a suggestion by Capt. David Semple, USAAF (dec'd), to increase the drag, gave a stable model. This modification involved the welding of angularly disposed trapezoidal drag-plates into the box tail of the bomb. No release failures occurred, and the fusing mechanisms tested proved to have great promise.

7.90 In the period between these tests and the next held in October, design, procurement and testing work continued at Los Alamos. When by midsummer it became certain that the plutonium gun assembly would not be used, the remaining models were the Little Boy and the Fat Man. A new model Fat Man was developed

in this period, to improve flight characteristics and simplify mechanical assembly. This was the "1561". It consisted of a spherical shell made up of two polar caps and five equatorial zone segments, machined from dural castings. The assembled sphere was enveloped by an ellipsoidal shell of armor attached at the equator. The tail was bolted to the ellipsoid. The electrical detonating and fusing equipment was mounted on the sphere in the space between the sphere and the outer ellipsoid.

Experiments on the 10 gram scale also showed that UI_4 could be reduced with calcium metal using the same procedures as were used for the fluoride and chloride.

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Argon was used as an inert atmosphere in the bomb. The amount of iodine used and the heating cycles varied with each scale of reduction. It was found that magnesium oxide crucibles were the most satisfactory. Methods for the preparation of the several types of MgO crucibles were developed, the methods later being used by MIT for the routine preparation of the large scale crucibles.

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URANIUM ALLOYS

8.25 Alloys were sought which would have better physical properties for fabrication than the unalloyed metal. Beginning in November 1943, an intensive program was undertaken on the preparation of uranium alloys in various percentage compositions. Mixtures of uranium with molybdenum, zirconium, columbium and rhenium were obtained which indicated that many desirable properties could be produced in such alloys. In particular, extended investigation of the uranium molybdenum system showed that it had a much higher yield strength than pure uranium. The emphasis on this work, however, was not maintained and in the fall of 1944 most of the alloy research was dropped, as ordinary uranium was found to have adequate physical properties.

Plutonium Purification

8.26 The plutonium purification procedure, as distinguished from the more general chemistry of plutonium, was primarily the work of the Uranium and Plutonium Purification Group at Los Alamos. Early in October 1943, the first small quantities of plutonium arrived at the Laboratory and shortly thereafter

intensive work on stand-ins was initiated to permit the members of the Purification Group to determine and improve their techniques. The stand-ins used included uranium, cerium, lanthanum, zirconium and thorium. Uranium was used principally in the investigation of ether extraction methods; thorium and cerium were employed to test solubilities and purification by various precipitations. In metallurgical work, cerium trichloride was used as a stand-in for plutonium trichloride and in other small scale work cerium tetrafluoride was used as a stand-in for the corresponding plutonium salt.

8.27 The development of plutonium purification procedures is readily divisible into three parts: wet processing, dry processing and, by reason of the cost of the material, a recovery process. The intensity with which the division attacked the difficult problem of plutonium chemistry was rewarded by the complete development in the first period of the wet chemistry procedure finally used in large scale work. By August 1944, however, the dry process and recovery procedures had not been completely determined. The former was still in the formative stage of development and the latter, while satisfactory, was greatly simplified by later research (17.18-21).

THE WET PROCESS

8.28 The plutonium output from Clinton and later from Hanford was received at Los Alamos as a highly viscous mixture of decontaminated and partially purified nitrates. These nitrates consisted of about 50% +4 plutonium and 50% +6 plutonium. This material had to be dissolved out of its stainless steel shipping container, diluted and a sample removed for radio-assay purposes. This preliminary work generally required between three and four days and when completed permitted further processing by the wet purification steps. A wide variety of purification procedures were investigated. Early in 1944 the first tentative procedure involved a double sodium plutonyl acetate precipitation followed by a double ether extraction employing sodium nitrate as a salting-out agent. Potassium

bichromate was originally used to go from +4 to +6 plutonium ion, but this was soon superseded by sodium bromate plus nitric acid. For selective reduction from +6 to +3 plutonium, hydrogen iodide or potassium iodide in acid solution were used throughout the work.

8.29 The first major difficulty encountered was the need of a process to separate small amounts of uranium impurity from large amounts of plutonium. Various compounds such as carbonate, peroxide, fluoride, iodate and oxalate were investigated. The iodate $Pu(IO_3)_4$ was found to give 99.5 per cent removal in two precipitations with a selective reduction step, but it proved extremely difficult to convert this compound to sodium plutonyl acetate. Finally the precipitation of the +3 oxalate provided the solution to the problem and became an important part of all future processes.

8.30 The procedure as outlined gradually changed. Two oxalate precipitation steps were incorporated. An ether extraction and a plutonyl acetate step were dropped. By July 1944, completely enclosed one-gram and eight-gram apparatus was being set up, and the process known as the "A" process had taken form. This involved reduction to +3 oxidation state, oxalate precipitation, oxidation to +6 oxidation state, sodium plutonyl acetate precipitation, ether extraction from nitric acid and ammonium nitrate solution, reduction to +3 oxidation state, and a final oxalate precipitation. The process gave yields of about 95 per cent. The product was then turned over to the dry chemists as an oxalate slurry. The residue supernatants were returned for recovery.

8.31 The reason for the development of enclosed apparatus was primarily the plutonium health hazard (9.30).

THE DRY PROCESS

8.32 Since the conversion of the wet oxalates to the dry halide of plutonium led to a product which the metallurgists had to reduce to metal, there was collaboration between these groups in the attempt to settle on a suitable

compound for reduction. The tetrafluoride was decided upon in July 1944. The preceding investigations covered the range of most of the halides of plutonium (for calcium bomb reduction) and PuO_2 (for carbon reduction). Plutonous chloride and bromide were rejected because they were highly hygroscopic. The carbon reduction of the oxide was also dropped.

8.33 The preparation of the tetrafluoride underwent continual development and improvement during the course of the work of the Laboratory. It was prepared variously from the nitrate, oxalate and oxide by the use of anhydrous hydrogen fluoride. The conversion of the nitrate was poor, and research concentrated on the conversion of the oxalate and oxide. The final choice of the oxide occurred early in 1945, as did the final development of production methods (17.21).

RECOVERY OF PLUTONIUM

8.34 Except for the peroxide recovery method (17.22) all procedures were developed before August 1944, by the Recovery Group. Recovery was necessary from the supernatants of plutonium purification and from liners and slags of the metallurgists. From the supernatants the procedure involved concentration of the plutonium with subsequent purification. Reduction was made with sulphur dioxide followed by a precipitation with sodium hydroxide. Treatment with aluminum hydroxide as carrier brought down further amounts of plutonium. About one milligram per liter remained in solution, and these secondary supernatants were stored. Purification steps originally involved iodide reduction oxalate precipitation, oxidation ether extraction, sodium plutonyl acetate precipitation, iodide reduction, and a final oxalate precipitation. After these steps had been carried out, the purified product went directly to the dry chemists.

8.35 Work on liner and slag recovery showed quite early that complete solution would be necessary for good recovery. The major difficulty was to remove iodine and iodide ion before solution. The first method developed was

one of CCl_4 or sodium sulfite extraction for the I_2. Following this, liner and slag were dissolved in hydrochloric or nitric acid, followed by a precipitation of $Pu(OH)_4$ from a solution almost saturated with ammonium nitrate. This precipitation was carried out at a high enough hydrogen ion concentration to leave most of the magnesium (from the magnesia liner) in solution.

Plutonium Metallurgy

8.36 In March 1944 the first bomb reductions of PuF_4 and $PuCl_3$ were undertaken by the Uranium and Plutonium Metallurgy Group. This was the first direct metallurgical work with plutonium, although previous work had been done with stand-ins (8.22). Emphasis was placed at this time on the electrolytic method and chloride reduction.

8.37 Research on the physical properties of plutonium metal began in April 1944 and was to prove of major importance because of the unique physical properties of the metal. By May 1944 metal yields were over 80 per cent by a number of methods and the shift of interest to the stationary bomb reduction method began. Extensive work on remelting, as a final purification step, centered interest on the use of refractories which would not contain light element contaminants. This eliminated the usual refractory-materials. One of the principal refractory materials investigated in these studies was cerium sulfide (8.53).

8.38 Discrepancies found in the density of various metal samples produced the first hint of the existence of plutonium allotropes. By June, metal obtained from $PuCl_3$ using calcium as a reducing agent and subsequent remelting in cerium sulfide crucibles came within a factor of ten in meeting the prevailing purity specifications. The alpha and beta allotropes of plutonium were definitely established at this time and the PuO_2 plus carbon reduction method developed in the High Vacuum Research Group came into temporary prominence.

PLUTONIUM REDUCTION

8.39 As with uranium, two general methods of metal preparation were investigated; the electrolytic process and the metallothermic process. The latter process was again divided into two methods; the centrifuge method and the so-called stationary bomb method. An additional method was also studied in which the oxide of plutonium was reduced and the metal distilled.

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8.40 Electrolytic Process: Investigations of the electrolytic reduction of plutonium on the 50 mg-1 gram (of metal) scale gave recovery yields of ~50 percent. The bath consisted of 24 percent $PuCl_3$ in a solvent containing 48 percent $BaCl_2$, 31 percent KCl, and 21 percent by weight of NaCl. The metal obtained was in the form of droplets and usually contained small amounts of the cathode element. With the discovery of Pu^{240}, the work on the electrolytic process was stopped in favor of the metallothermic process. Details of the electrolytic process are given in La-148.

8.41 Centrifuge Reduction Method: As in the case of uranium (8.24), the purpose of this method was to prepare plutonium metal on the small scale (50 mg-1 gram of metal) by taking advantage of the increased g value for the collection of the small amounts of metal. Successful reductions of plutonium were made using $PuCl_3$ or PuF_4 with Li as a reductant. Calcium reductions of these halides using iodine as a booster were not as successful. The plutonium metal prepared by the centrifuge method was the first plutonium metal prepared on any scale larger than a few micrograms. With the development of the 0.5 gram scale stationary bomb method for the preparation of plutonium, the centrifuge method was abandoned. However, the centrifuge served its purpose at a time when it was needed most. (Appendix 7 , No. 27).

8.42 Stationary Bomb Method: The work on this problem was started in March 1944; however, much preliminary work had already been done using uranium as a stand-in. As in the case of uranium, the problem of plutonium reduction involved the development of refractory crucibles for the reaction, the design of suitable bombs, the investigation of raw materials for the reaction, and the development of techniques of each scale of reduction studied. During the research on plutonium, cerium and lanthanum were also used as stand-in elements, and techniques were developed to prepare both metals from their chlorides and fluorides on all the scales given below. The chloride of plutonium was used for the first successful reductions of plutonium by the stationary bomb method. These reductions were done on the 0.5, 1, and 10 gram scale. The fluoride was then investigated and found to be more satisfactory because of its non-hygroscopic nature and greater ease of preparation. Successful techniques were developed for the reduction of plutonium on the 0.5, 1, 10, 25, 160, 320, and 480 gram scales. The average yields in a single button of clean metal ranged from 95% for 0.5 gm, to 99% for the 320 and 480 gram scales. The bromide was also reduced on the 1 gram scale, but with lower yields. The methods developed here from the reduction of PuF_4 are now used for the routine production of pure plutonium metal. (Appendix 7 , No.28)

8.43 The oxide reduction method involved the reduction of plutonium oxide with carbon or silicon and distilling the resulting metal onto a cold finger. This method gave yields on a small scale (5 gram) of 30 to 90 percent of spectroscopically pure plutonium. The discovery of Pu^{240} called a halt to this ultra-high purity method.

8.44 In addition to reduction techniques, remelting techniques were also investigated. A large part of this work was in the choice of crucible materials. Remelting was important because of the need for metal with uniform physical properties and because further impurities (e.g. magnesium) were removed in the process.

8.45 Extensive work was carried out by the Los Alamos metallurgists on the physical properties of plutonium metal. Early results yielded inconsistent data from measurements on different metal samples. In July 1944 these inconsistencies were partially explained by proof of the existence of alpha and beta allotropes, with a transition from the room-temperature alpha phase to the beta phase at between 100-150° C.

Miscellaneous Metallurgy

8.46 A good deal of outstanding metallurgical work was done at Los Alamos outside the narrow field of uranium and plutonium, principally by the Miscellaneous Metallurgy Group. Many of the jobs undertaken were more or less routine, but these routines had to be developed through the solution of difficult minor problems. The development of uranium hydride compacts has been discussed in connection with uranium metallurgy (8.19-21). Work on the compacting of boron neutron-absorbers was undertaken in August 1943. Development of beryllia tamper material for the water boiler was begun in the same month. The formation of high-density beryllia bricks for this became a production job in December 1943 and was completed in February 1944. DELETED DELETED DELETED In May, because of the difficulties encountered in obtaining refractories from other sources, magnesia liners and cerium sulfide crucibles were developed for the plutonium metallurgy program.

BORON COMPACTS

8.47 The remarkable properties of boron^{10} as a neutron absorber gave this material several uses in the laboratory. DELETED DELETED DELETED The potential importance of boron^{10} was such that its procurement was undertaken quite early (4.20), and studies were begun of means of compacting it. The oxide, the carbide and the element were used as starting materials. DELETED DELETED DELETED

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BERYLLIA COMPACTS

8.49 One of the accomplishments of the Miscellaneous Metallurgy Group was the development and production of beryllia bricks for the water boiler tamper and scattering experiments. Since these bricks were to be used as tampers high density was desirable. Beryllium metal would have been the best tamper material. Use of the metal at that time, however, would have virtually exhausted the country's supply.

8.50 Various methods of obtaining high density were tried, among them impregnation with magnesium fluoride but the fluoride was undesirable from a nuclear point of view. A method of impregnation with beryllium nitrate followed by ignition proved rather poor.. The method finally chosen was a hot pressing technique, somewhat unusual for a refractory material.

8.51 Experimentally, the bricks were prepressed in a steel mold, then hot pressed in graphite at 1700° C at pressures in the neighborhood of 1000 pounds per square inch for five to twenty minutes. Fifty-three bricks were made for the water boiler tamper, shaped to fit around the 12-1/16 inch sphere of the boiler. For this production job the method was a variation of the method described above. The density averaged 2.76.

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CRUCIBLE AND REFRACTORY RESEARCH

8.53 The purpose of this important work was to find materials for

crucibles and liners which would not introduce contaminants into purified uranium and plutonium. Wetting, sticking and thermal sensitivity had also to be considered. In this program a great many substances were investigated including cerium sulfides, calcium oxide, magnesium oxide, tantalum, graphite, a tantalum-thorium nitride mixture, zirconium nitride, thorium sulfides, beryllia, uranium nitride, thoria, tungsten carbide, tantalum carbide, titanium nitride and many others. Cerium sulfide was one of the really hopeful materials found during this period and effort was concentrated on trying to improve the fabricated material's resistance to thermal shock, its main weakness.

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MISCELLANEOUS SERVICE ACTIVITIES

8.54 The metallurgists prepared a great variety of materials for physics and ordnance experiments. These involved machining, heat treating, metallographic studies, casting of various metals, electroplating, miscellaneous plastic preparations and powder metallurgy. Metallographic methods for uranium and plutonium studies were essentially new. This work was done mainly by the Heat Treating & Metallography Group, and the Miscellaneous Metallurgy Group.

Radiochemistry

8.55 Prior to August 1944 the work of the Radiochemistry Group fell into the following categories: foil preparation, boron trifluoride preparation, development of sensitive methods of neutron detection, the chemistry of initiators, the chemistry of the water boiler and the planning of remote control methods for the handling of radio-lanthanum.

FOIL PREPARATION

8.56 The preparation of thin foils for physical experiments was a service activity but, as such, involved a great deal of arduous and delicate work, and continued research on methods. Foils of a large number of different

substances were made with emphasis on the oxides of uranium and plutonium. Among other substances were boron, protoactinium, uranium 233, neptunium 237 and thorium.

8.57 The principal methods of foil preparation used were evaporation, electrodeposition and the "lacquer" method, -- the last so-called because in it an alcohol metal salt solution is mixed with a nitrocellulose lacquer, spread in a thin film, and ignited to oxide.

8.58 Boric oxide foils were prepared by the lacquer method. Aluminum boride foils were prepared by heating aluminum foils in boron trifluoride. Boron was deposited on tantalum and tungsten foils by thermal decomposition of diborane. This work with boron was exceptionally difficult, requiring the production of very thin foils with accurately known mass. It was developed by Horace Russell, Jr. (deceased). Deposits of the oxides of thorium, uranium and plutonium were prepared by the lacquer technique, as well as by electrolytic methods.

8.59 The virtuosity of the chemists engaged in this work was remarkable. They turned out large numbers of foils that accurately met the physicists' specifications, including unusual geometries. In many cases the data supplied with the foils by the chemists were as important in interpreting physical experiments as any of the physical measurements made with them.

CHEMISTRY OF INITIATORS

8.60 It was assumed from the beginning that a neutron initiator would be used with the bomb to provide a strong neutron source that would operate at the instant of optimal assembly. Naturally, the first initiators were designed for the gun (7.40). The type of initiator, if any, to be used with the implosion was not settled until after August 1944. The principal mechanism adopted for the initiator was the properly timed mixing of alpha-radioactive material with a substance that would support the (α ,n) reaction.

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SENSITIVE COUNTERS

8.61 The radiochemists developed a neutron counter based upon the Szilard-Chalmers reaction. In this reaction a nucleus absorbs a neutron. It then loses energy by gamma emission and the recoil of the atom frees it from its chemical bonds. This dissociation permits the chemical separation of the reaction product and the measurement of its induced radioactivity. The sensitivity of this reaction as a neutron counter is high because it permits the absorption of neutrons in a large volume of material. Until early 1944 ethylene bromide was used as the basis of the procedure. At that time work began with potassium permanganate. A detection efficiency of about ten per cent was eventually obtained.

8.62 Sensitive boron trifluoride counters were developed cooperatively by the Radiochemistry Group and the Radioactivity Group. It was the job of the

radiochemists to prepare this substance in an extremely pure form. High purity of the product made possible effective operation at high boron trifluoride pressures. The first such counter, the "bucket chamber", had a one or two per cent efficiency. Later, the radiochemists developed another counter themselves (17.37).

WATER BOILER CHEMISTRY

8.63 Since the water boiler contained active material in aqueous solution, there were a number of chemical problems associated with the physical ones. The choice of a compound to use, the original purification of the material, the prevention of corrosion of the containing sphere, and methods of decontamination and analysis were the main matters requiring investigation.

8.64 In the original boiler it was decided to use uranyl sulfate for the following reasons: the solubility and solution density were higher than those of the nitrate; there was, moreover, some saving in critical mass because the neutron capture cross-section is smaller for sulfur than for nitrogen.

8.65 Purity requirements were not strenuous except for two or three light elements. They were calculated by the rule that no impurity in the solution should absorb more slow neutrons than the sulfur in the sulfate.

8.66 Work on corrosion determined that stainless steels were suitable for boiler container and piping. The effects of working, welding and annealing were studied and it was shown that weight loss dropped to zero after a few days time. Boiler parts were therefore pretreated with normal isotopic uranium sulfate solution and corrosion difficulties were substantially eliminated.

8.67 The hydrates of uranyl sulfate were investigated in order to predict volume changes from final additions of active material to the boiler "soup". A stable hemi-hydrate was found with less water than the normal precipitate from saturated solutions.

8.68 The refractive index of uranyl sulfate solutions was investigated

to develop a rapid method of keeping track of amounts of uranium in solution. With monochromatic light through pure solutions, concentration would be measured to 0.1 per cent.

8.69 In the actual setting up of the boiler in May 1944, the chemists made all additions and removals of "soup", keeping accurate records of concentration by the refractive index and by gravimetric analysis method. When the activity of the boiler reached the critical point the concentration was measured by refractrimetry and checked by other methods. The control rod was calibrated by adding small weighed increments of sulfate and determining the critical setting of the control rod for each increment.

RADIOLANTHANUM

8.70 Before August 1944 no test shots were fired in the RaLa program (7.74). Design of a "mechanical chemist" for remote control work with this highly radioactive material began, however, as early as May 1944. By August the apparatus, at the Bayo Canyon site, was almost complete. Further account of this work is found in Chapter XVII.

Analytical Methods

8.71 The high purity analytical program was organized on the basis of theoretical considerations already reported (1.73). The plan to use plutonium originally demanded an extremely low rate of neutron emission, estimated to be 3 neutrons per minute per gram. Tolerance limits for each element were calculated by polonium alpha-particle bombardment of element targets and calculation of the neutron yield, thus obtaining the amount of element necessary to give 3 neutrons per minute.

8.72 The tolerance limits for 13 elements, not counting the rare earths, were found to be below 100 parts per million. In addition, effects are additive. It was generally agreed that the sensitivity of analytical methods should be one tenth of tolerance. Since early experimental production would be very small, and analytical samples might well be no larger than 1 milligram, it

was evident that research on new submicro-analytical methods was necessary.

8.73 In general, high sensitivity was sought rather than high precision. The analytical chemist's greatest difficulty was to identify and determine approximately the interfering elements. When this was done the purification procedure could be modified to eliminate such elements or at least cut them down considerably.

8.74 Unusual factors entered into such submicro work. Reagents had to be unbelievably purified in order that the presence of a particular impurity should not become the limiting factor of the method. Contamination was probably the major difficulty since most of the worst elements are prevalent in any ordinary experimental environment (atmospheric dust and fumes, floor scuffings, etc.). The laboratories were equipped with precipitrons. Floors and walls were kept very clean. A special sub-group of the CM-1 Service Group was devoted to light element contamination control and investigation. Theirs was the job of making certain that dust in laboratory air was at a minimum and that laboratory personnel were not unconsciously causing some significant contamination. Control tests were run on dust deposition in the laboratories; the humidifying system was found to bring in contamination and was stopped. Shoe covers were adopted to avoid floor scuffing and methods of cleaning floors were improved.

8.75 Some of the analytical methods used at Los Alamos were developed at the Chicago Metallurgical Laboratory. Rather close liaison existed between the two projects in this particular field. One of the outstanding analytical developments at Los Alamos was the vacuum method for carbon and oxygen analysis.

8.76 The analytical methods involved in the early work at Los Alamos may be divided into the following categories:

1. Spectrochemical Methods.

   A. Plutonium

(1) The cupferron and gallic acid methods--trace analysis for light element impurities.

(2) The direct copper-spark method.

B. Uranium

(1) The gallium-oxide-pyroelectric method.

(2) Determination of rare earths in uranium.

(3) Cupferron precipitable refractories in uranium.

C. Miscellaneous

(1) Impurities in graphite by gallium-oxide-pyroelectric method.

(2) Determination of fluorine in uranium and calcium (the strontium fluoride band method).

2. Colorimetric Methods.

A. Determination of phosphorus in uranium and plutonium.

B. Determination of microgram quantities of acid soluble sulfide sulfur.

C. Determination of iron in plutonium.

D. Determination of sub-microgram quantities of boron in calcium, uranium and plutonium.

3. Gravimetric Methods.

A. Determination of molybdenum in uranium-molybdenum alloys.

B. Determination of carbon in uranium tetrafluoride..

4. Assay Methods.

A. Radioassay.

B. Photometric assay.

5. Gasometric Methods.

A. Oxygen.

B. Carbon.

1. SPECTROCHEMICAL METHODS

8.77 These methods were developed by the Analysis Group. Copper electrodes for use with spark excitation had been used at Berkeley in the first spectrochemical analysis of plutonium. The direct copper spark method as used at Los Alamos was a Chicago development. It had been shown at Chicago that plutonium could be extracted by cupferron and chloroform. The method of making this separation before sparking was conceived at Chicago but developed at Los Alamos. The pyroelectric-gallium-oxide method was developed at Los Alamos.

A. Plutonium analysis

8.78 The cupferron and gallic acid methods were first used (early 1944) as co-methods in developing routines for trace analysis of the light elements. The former was chosen as standard. When, in August 1944, purity standards were relaxed, the need for very sensitive methods disappeared and further research on their improvement ended. The cupferron method is discussed in Chapter XVII.

8.79 The direct copper spark method was used throughout the Laboratory history. In this procedure plutonium is evaporated on copper electrodes and the spark-spectrum photographed in the 2500-5000 angstrom range. The quantities of impurities are estimated by measurement of spectral line densities. By the end of this history, this was the only method available for the determination of thorium and zirconium. It was used for preliminary determination of impurities in incoming Hanford plutonium solutions.

B. Uranium analysis

8.80 Except for a short time early in 1944 when the gallic acid method of analysis was tried for a while, the pyro-electric method was the means of overall purity analysis of uranium. In this method the oxide mixed with gallium oxide is arced from a crater in a graphite electrode and estimates are made spectrographically. Volatilization of impurities along with gallium occurs in a manner analogous to steam distillations but the complex uranium spectrum

does not appear. Volatile compounds lost in ignition to the oxide are not determinable.

8.81 Rare earth determination of high sensitivity was made possible by a method which removed other impurities, followed by examination of the spark spectrum.

8.82 Cupferron-precipitable refractories --titanium, zirconium and iron-- were separated from other impurities by this method and examined in the copper spark.

C. Miscellaneous

8.83 Graphite purity analysis was developed as an adjunct of the PuO_2 graphite metal reduction (8.42) and dropped with the latter.

8.84 The strontium fluoride band method was the only successful method discovered for fluorine analysis. This method involved the absorption of fluorine in sodium hydroxide. The sodium fluoride is arced in the presence of excess strontium oxide and the amount of fluorine estimated by comparing strontium fluoride band head intensities with a standard. This method seems applicable to a number of materials but at Los Alamos has only been applied to uranium and calcium.

2. COLORIMETRIC METHODS

8.85 Phosphorus in uranium and plutonium was estimated by a colorimetric method depending on the formation of molybdenum blue from orthophosphate.

8.86 Microgram quantities of acid-soluble sulfide were estimated by a colorimetric method. This depends upon the conversion of hydrogen sulfide into methylene blue, which is determined spectrophotometrically.

8.87 Iron was determined spectrophotometrically in the presence of + 3 plutonium after reduction to the ferrous state with hydroxylamine.

8.88 Boron in calcium, uranium tetrafluoride and plutonium were determined by distillation as methyl borate from a special quartz still. The distillate was trapped in calcium hydroxide solution and the boron estimated by a colorimetric method.

3. GRAVIMETRIC METHODS

8.89 Gravimetric methods were used for the determination of molybdenum in uranium-molybdenum alloys and of carbon in uranium tetrafluoride.

4. ASSAY METHODS

8.90 Before August 1944 radioassay was the means of keeping track of plutonium quantities received, while a true analytical method, photometric assay, was being investigated. This method, however, did not yield encouraging results and was later proved quite untrustworthy. Hence, radioassay was continued. This method involved the determination of the quantity of an aliquot of the material by measurement of its alpha activity.

5. GASOMETRIC ANALYSIS

8.91 Description of the procedures involved in this work is limited by the extreme complexity of the apparatus used. The apparatus used for oxygen and for carbon micro-determinations can be classed among the most complicated analytical set-ups in the history of chemistry.

8.92 The oxygen method developed by the High Vacuum Research Group solved one of the most pressing analytical problems at Los Alamos --the development of a dependable micro-method for oxygen determination. The overall method was not new but its application on a micro-scale, the accuracy obtained, and the furnace tube developed were quite new.

8.93 The procedure involved vacuum fusion of a sample in a graphite crucible and analysis of the gases evolved. Oxides react with graphite at high temperatures, giving carbon monoxide. Determination is made of this compound.

8.94 The apparatus was composed essentially of two parts, a high vacuum system (10^{-8} centimeters) and a somewhat revised Prescott microgas analyzer. Either one of these systems could be broken from the line independently. The sample size was about 50 milligrams and sensitivity of the method was about ten parts per million. In the original procedure the crucible and furnace tube were put in place, the sample was put in a dumper bucket, and the tube sealed. The sample was dropped into the crucible after the latter was suitably degassed. The gas was then collected for analysis.

8.95 The apparatus for carbon analysis in plutonium was simply a modification of the oxygen apparatus. The sample was burned in oxygen from mercuric oxide in a low-carbon platinum crucible. The gaseous products were then analysed by the Prescott apparatus. In this case the sensitivity was five parts per million or less.

CRYOGENY

8.96 At the very beginning it had appeared that the development of a deuterium super-bomb might prove feasible and necessary during the wartime course of the Laboratory. As the great difficulties attending this development became more apparent, and as the energy of the Laboratory was absorbed in the prior problem of the fission bomb, the experimental side of the "Super" project was gradually brought to a standstill. Except for new cross section measurements later made in F Division (13.38) this program was in fact limited from the beginning to investigation of the preparation and properties of liquid deuterium. Locally, it was virtually limited to the design and construction of a deuterium liquefier. This was a Joule-Thompson liquefier patterned after that built by W. F. Giauque at the University of California. It consisted of an ethane, a liquid air, and a liquid hydrogen (or deuterium) cycle. The first two cycles were completed by the beginning of 1944. The hydrogen cycle was completed in April 1944 and tested. Although the original design was for a

capacity of 35 litres an hour, at the altitude of Los Alamos (7300') it produced only 25 litres, a loss which could be compensated for by additional compression if necessary.

8.97 Because of limitations of space and personnel, the physical investigations relevant to the problem of producing and storing liquid deuterium were carried out under contract by Prof. H. L. Johnston at Ohio State University. These included studies of the ortho-para conversion of liquid hydrogen and deuterium, of hydrogen-deuterium exchange problems, of the high-pressure low temperature equation of state for hydrogen and deuterium, of the heat of vaporization of liquid deuterium, of the Joule-Thompson coefficients of hydrogen and deuterium. Experiments were made on the properties of thermal insulators at low temperatures. Studies were also made of the long-term operation of hydrogen liquefaction equipment.

8.98 Work was begun under the Ohio State contract in May 1943, and continued through the life of the Project. The contract was renewed at six month intervals. As of September 1945, investigations still incomplete were planned for completion by the end of that year.

8.99 After the first test of hydrogen liquefaction in April 1944, no further developments in cryogenic work occurred at Los Alamos. Long and his group were assigned to other problems. On the basis of his assurance that with existing equipment he could produce amounts of the order of 100 litres of liquid deuterium in two months, and amounts of the order of 1000 litres in eight months, cryogenic work was formally suspended in September 1944.

Chapter X

THE PERIOD AUGUST 1944 - AUGUST 1945

TECHNICAL REVIEW

Introduction.

10.1 As the previous chapter will testify, the growth of the Laboratory plant and program during the period reviewed was determined primarily by the urgency and difficulty of the implosion program. The status of that program at the end of the previous period has been outlined in Chapter IV (4.46-4.53). By comparison of this situation with that existing in July, 1945, when the first implosion bomb was tested and found successful, it is clear that by the latter date a major technological victory had been won. The period reviewed, however, is not completely defined by that victory. The success of the Trinity test was possible only in the flowing together of several parts of the Laboratory's work. The success of the combat missions over Japan, moreover, presupposed that of the entire delivery program. Finally, it must not be forgotten that the first atomic weapon was the "Little Boy" gun assembly, developed during this period largely by a single group. Because it was relatively smaller and more straightforward than the implosion, its accomplishments will be reviewed first.

Gun Program.

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10.2 During this last year of the war the gun program was consolidated under one group, the Gun Group of the Ordnance Division. This group completed the design of the U^{235} [redacted] gun assembly, tested its components at reduced and full scale, undertook their final engineering and procurement, and after an elaborate program of final field and drop tests produced a weapon more certain of high-order operation, without having been tested, than the more radical implosion design tested at Trinity. During the earlier period of the Laboratory

the possibility of a U^{235} implosion bomb had not been ruled out. With the acquisition of accurate means of calculation and reliable cross section data, it became evident that such an implosion would be considerably less efficient than the plutonium implosion. This fact, added to the uncertainties of the whole implosion program, made it seem desirable to plan for the use of U^{235} by the gun method alone. Toward the end of the war the possibility of composite (U^{235} + Pu^{239}) implosion bombs was considered (11.2, 20.2). By the time of the "freeze" of the Laboratory program in February, 1945 (11.16), the decision was final to use U^{235} only in the gun model.

10.3 This quiet and efficient group continued at the center of an affiliated program in the Research Division, the Theoretical Division, other groups of the Ordnance Division, and in the Alberta Project (Ch. XIX). From the Research Division, Group T-2 was able to obtain information on the nuclear properties of U^{235} [redacted] sufficient to provide accurate data for critical mass calculations and calculation of the amount of material that could be safely used. From the sphere multiplication experiments of R Division a still more accurate calculation of the critical mass could be obtained, by extrapolation. The gun was "mocked" by the model experiment in the same division, and this provided an integral check of the calculations of the performance of the weapon, including predetonation probability. The finished projectile and target, finally, were brought to the critical point by the Critical Assemblies Group of G Division shortly before shipment to Tinian for combat use. This assembly was a final check of the accuracy of predictions as to the point at which the system would become supercritical. Reliable efficiency calculation was made possible by theoretical and experimental estimation of the initial multiplication rate of the fully assembled bomb.

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10.4 The fabrication of the projectile and target was the responsibility of members of Groups CM 2,7, and 11 of the Chemistry and Metallurgy Division.

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Fabrication included the forming of the active material into pieces of proper shape and purity [DELETED] [DELETED] and the steel casing that housed the target. The development of the initiators used to assure an initial neutron source was the work of the Gun Group in collaboration with the radiochemists. The final design of the outer case, originally the responsibility of the Engineering Group of the Ordnance Division, was almost entirely transferred to the Gun Group during this period. Responsibility for the fusing and detonating system remained with the Fuse Group of the Ordnance Division. The Gun Group and the Fuse Group collaborated in the drop tests of the "Little Boy" carried out as part of the program of Project Alberta.

The Plutonium Bomb

10.5 At the beginning of the period under discussion the hope for a successful implosion was so low that F Division was given the responsibility, soon after its creation, of investigating even the slim possibility that as an alternative, an autocatalytic system of assembly utilizing plutonium might be found meritorious. The desirability of such systems was not immediately evident and in the meantime the Weapon Physics Division, the Explosives Division, and the Theoretical Division were preparing themselves for a direct attack on the implosion problem.

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10.6 Prediction based on the analysis of Clinton plutonium led to the expectation that the Hanford plutonium would produce [DELETED] neutrons per second in bomb-amounts of plutonium, from the spontaneous fission of Pu^{240} alone. Light impurities would produce additional neutrons, but purification would keep this contribution small compared to that from spontaneous fission. Only the implosion would be fast enough to assemble the plutonium in a time short enough to avoid predetonation.

10.7 The "direct attack" on the implosion problem included the continuation of small scale implosion studies in the new X Division, with particular emphasis on interpreting the causes of jets and irregularities,

including the careful investigation of the source of timing errors in multi-point detonation and their contribution to asymmetries. The first lens test shot was fired in November, 1944. In the meantime G Division was getting under way its many-sided effort to examine the implosion experimentally, was beginning work on electric detonators, and was planning the hydride critical experiments as a step to eventual critical assemblies of active metal. At the same time the Theoretical Division was completing its studies of the "ideal" implosion (which began with a spherically converging shock-wave), and was turning its attention to the theoretical interpretation of the jets and asymmetries that had been found in less-than-ideal experimental implosions.

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10.10 In the Explosives Division means for preventing the development of irregularities were under investigation.

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Thus although there was as yet no sure path to success, hopeful directions of development had been marked out.

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10.16 At the end of February, 1945, a conference was held at Los Alamos, with General Groves present, at which it was decided that the time had come to freeze the program of the Laboratory in order to meet the July deadline for the first bomb test. At this conference it was decided to concentrate all

further work on the solid core lens implosion with a modulated nuclear initiator. DELETED DELETED DOE b3) DELETED DELETED

10.17 At the same time a detailed schedule of all implosion work was decided upon. DOE b3) DELETED DELETED DELETED By April 2 full scale lens molds had to be delivered and ready for full scale casting. Full scale lens shots had to be ready by April 15, to test the timing of multipoint electric detonation. Hemisphere shots had to be ready by April 25. The DOE b3) detonator DELETED had to come into routine production between March 15 and April 15. By the latter date large scale production of lenses for engineering tests had to be begun. A full-scale test, by the magnetic method, had to be made between April 15 and May 1. Full scale plutonium spheres had to be fabricated and tested for their degree of criticality between May 15 and June 15. By June 4 the fabrication of highest-quality lenses for the Trinity test had to be under way. The Trinity sphere fabrication and assembly should begin by July 4.

10.18 To meet the stringent requirements of this program, the Cowpuncher Committee (9.8) was set up March 1, to "ride herd" on it. DOE b(3) DELETED DELETED DELETED

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DELETED The feasibility of a modulated initiation was accepted April 27. DELETED DELETED DOE b(3)

DOE b(3) DELETED Full scale lens molds were completed in May, after innumerable procurement delays. Timing measurements of lenses were made with successful results shortly thereafter, but also delayed. DELETED

DOE b(3) DELETED DELETED At the beginning of June the first "urchin" initiator DELETED filled with DELETED DOE b(3)

DOE b(3) polonium. By June 12 two full scale plutonium hemispheres were tested for neutron multiplication, something over two weeks late. The delays referred to arose primarily because of the difficulty of procuring good lens molds on schedule. The result was a shortened time for final engineering tests. But the Trinity test was made, actually four days ahead of the target date - July 20, 1945 - assumed in making the above schedule.

Theoretical & Experimental Physics

10.19 During the period reviewed the Theoretical Division was able to bring to a successful close its earlier investigation of the techniques for solving neutron diffusion problems with accuracy, reliability, and speed. The Division developed these techniques and similar refinements in the means of treating the other theoretical problems involved in the implosion and the nuclear explosion. It was therefore able to give realistic guidance to the last phase of the experimental program, to the final weapon design, and to the preparations for the Trinity Test. In F Division the investigation of the Super continued at relatively low priority until the end of the war, when the freeing of men from other work made it possible to bring this work to partial completion. The results obtained indicated, in a convincing but not decisive way, that such a weapon is indeed feasible.

10.20 The experimental program in nuclear physics was continued by Divisions R and F. In R Division the original program of differential measurements was brought to completion: Neutron number measurements, spontaneous fission measurements, measurement of the fission spectrum and of fission cross sections, and scattering cross sections. Increasing emphasis was put on integral experiments, including tamper measurements and integral multiplication experiments, using solid spheres of U^{235}. In F Division, meanwhile, new measurements were made of the deuterium and tritium cross sections, which indicated a materially lower ignition temperature for tritium-deuterium mixtures than had been first obtained. The development of the high-power water boiler was carried through, and the instrument put into routine operation as a neutron source. Other work of the Division included cooperation with R Division on sphere multiplication experiments, and the preparation for radiochemical measurements at the Trinity test.

10.21 In G Division the Critical Assemblies Group carried through a program of critical assemblies with uranium hydrides of various compositions, and finally undertook the task of making metal critical assemblies with active materials to be used in the first bombs.

Chemistry and Metallurgy

10.22 The period under review saw, in the Chemistry and Metallurgy Division, the bringing to completion of full scale process and plant design, and full scale plant operation for production of active and tamper materials of both the U^{235} gun model and the Pu^{239} implosion model bombs. In addition to this the processing and handling of highly radioactive materials was carried out, both for the RaLa implosion test program and the neutron initiator program (polonium). As already pointed out the basic research program, plutonium purification, had already been solved on the research level by the time of the

discovery of Pu^{240} and the relaxation of purity requirements entailed by that discovery. The development of an efficient purification scheme was completed in the present period, as were the necessary techniques of metal reduction and metal forming. DELETED DELETED DELETED

10.23 The work of the Chemistry and Metallurgy Division, which in addition to the main program outlined above continued to do a great variety of service work for other divisions, was hampered by serious hazards to personnel from plutonium and polonium toxicity, and developed an elaborate system of monitoring buildings and examining employees. This health control work was hampered by increased crowding of facilities, until new plant facilities were made available.

The Trinity Test

10.24 The planning of the Trinity test became a high priority program in March, 1945. The Jornada del Muerto site for the test, called Trinity, had been selected in the previous Fall, necessary road and building construction had been undertaken, and a Military Police detachment had taken up residence at "Base Camp" in December 1944. Although most parts of the Trinity program were under way in March, there was a vast amount of work still to be done, in planning and instrumenting the great variety of mechanical, optical and nuclear records that had to be obtained. Several square miles of desert became the habitat of a complex laboratory, tied together in one vast system by thousands of miles of electrical wiring.

10.25 The first aim of the Trinity project was the rehearsal shot of 100 tons of high explosive that took place early in May. This provided a test of the organization for the final shot, and gave data for the calibration of blast measurements.

10.26 The information gained from this trial run proved valuable for the larger job ahead. As the July deadline of the test approached, larger and larger contingents of personnel arrived from Los Alamos to make ready the equipment for firing the bomb, for recording measurements of blast and shock, of spectographic and photographic information, and of nuclear data. The two hemispheres of plutonium were delivered from Los Alamos on July 11, and assembly of the high explosives began July 13.

10.27 The first atomic explosion was set off on the morning of July 16 after weeks of intensive preparation, and hours of tense waiting to see if the weather, which had turned bad the night before, would clear. The event can hardly be summarized more concisely than in 18.26 - 18.28.

10.28 With the impressive success of the Trinity test--whose yield certainly exceeded the expectations of most people, and was soon estimated to lie in the range 15,000 - 40,000 tons of TNT--the machinery of Project Alberta, the overseas mission, began to operate. Since the history of this project is largely an account of its test program, its liaison arrangements and general administration, the present technical summary ends with the successful completion of the Trinity program.

Chapter XI

THE THEORETICAL DIVISION

Introduction

11.1 During the second period, from August 1944 to August 1945, the Theoretical Division took part in the general expansion of the Laboratory to the extent of increasing the size of its groups, and adding three new Groups. In comparison with other divisions it had relatively little administrative history. It was not seriously involved with the general Laboratory problems of personnel, construction, transportation, nor was it involved except in an advisory way with the complicated procurement and scheduling operations of the Trinity test and Project A. It was therefore able to administer itself and do its work rather unobstrusively. Nevertheless it was an essential part of the final development program. As it gathered power from its earlier work, it was able to handle more realistic and complex problems with increasing efficiency, and to gain increased understanding of the difficult hydrodynamical questions involved in the implosion and the nuclear explosion, to refine its earlier calculations concerning critical masses and efficiencies, and to provide reliable interpretation of many integral experiments.

11.2 The Group Structure of the Division by August, 1945, was as follows:

T-1.	Implosion Dynamics	R. E. Peierls
T-2.	Diffusion Theory	Robert Serber
T-3.	Efficiency Theory	V. F. Weisskopf
T-4.	Diffusion Problems	R. P. Feynman
T-5.	Computations	D. A. Flanders
T-6.	IBM Computations	E. Nelson
T-7.	Damage	J. O. Hirschfelder
T-8.	Composite Weapon	G. Placzek

11.3 Group T-6 was added in September, 1944, to operate the IBM machines, under S. Frankel and E. Nelson. Frankel left this group in January

1945 to join the Theoretical Group of F Division. Group T-7 was formed in November, 1944, by a change of name. It was the Former O-5 Group, already for practical purposes a part of the Theoretical Division. At the time of this formal change of status, however, the group was given the responsibility for completing earlier investigations of damage and of the general phenomenology of a nuclear explosion. Group T-8 was added in May 1945 upon the arrival from Montreal of G. Placzek. The responsibility of this group was to investigate future fission bomb possibilities, specifically the levitated and composite core implosion, intended to use U^{235} (with Pu^{239}) more efficiently than would be possible by gun assembly.

Diffusion Problems

11.4 Although by August 1944 the essential difficulties of the one-velocity diffusion problem had been overcome, even the most economical method (expansion of the neutron distribution in spherical harmonics) was still rather expensive. A very great simplification of these calculations was accomplished by Group T-2 in the Fall of 1944, when an analytical expression was developed which by comparison with previously computed critical radii gave accuracies within 1-2%. This method made use of simple solutions for the shape of the neutron distribution far from boundaries (such as the boundary between core and tamper), and then fitted these solutions discontinuously at the boundary in such a way that the critical radius was given. From this time on, solutions for a great variety of critical radius or mass problems were proliferated extensively, and even reduced to nomographic form, permitting very rapid calculation.

11.5 Throughout the period under review various groups in the Theoretical Division, but particularly T-2, were concerned with special problems arising out of sphere multiplication experiments carried out in R Division.

These calculations had to take into account the variation of the average cross sections after the initial and each following collision of neutrons emerging from a central source. The number of neutrons coming out of the sphere as a function of the number of source neutrons was calculated for various size spheres and for various dispositions of the source. These calculations agreed very closely with the measured values; and as larger spheres of U^{235} became available, it was possible to extrapolate to the critical mass with very high accuracy (12.18-12.23).

11.6 Critical mass calculations for the hydride were developed, by Group T-4, as a means of predicting the size of the hydride critical assemblies carried out by Group G-1 of the Weapon Physics Division. When the first assemblies were made, a sizable discrepancy between the actual and the predicted critical size was found, of the order of 50%. Efforts to track down the cause of this discrepancy were partially successful; when newer values for the fission spectrum were used, the discrepancy was materially reduced. The conclusion was reached that the discrepancy arose from the sensitivity of the calculations to experimental errors in nuclear constants employed, and not from errors in the theory. This however was not certain, and some doubt was cast upon the adequacy of the methods employed. Hydride calculations, fortunately, were much more complicated than those for metal assemblies, and here the theorists had already demonstrated their ability to make accurate predictions.

The Gun

11.7 During the period under review relatively little new work had to be done on problems associated with the gun-assembly. Group T-2 remained in charge of this work, and prepared final calculations of the expected efficiency, including the predetonation probability. In the latter calculations

use was made of the integral experimental data obtained by Group R-1 from the gun model experiment (12.24).

The Implosion

11.8 By the beginning of the period discussed in this chapter, most of the calculations relating to the ideal implosion (starting with a converging symmetrical shock-wave at the outer edge of the tamper) had been completed, and it was possible to say that this part of the subject was almost completely understood. Implosion studies continued to be primarily the work of Group T-1.

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11.14 The paragraphs above give a qualitative account of how the background was prepared, within the theoretical division, for the "freeze" of design which occurred in February, 1945.

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11.15 These decisions, made only five months before the Trinity test, set several new problems for the Theoretical Division. The first of these was to determine the effect of temperature on the course of the implosion.

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DELETED DELETED DELETED The second was the question of proving the stability of convergent shock wave. Since it would be very difficult to get experimental information on the irregularities produced inside a solid core, it would be necessary to rely entirely on indirect evidence and on theory. The third theoretical problem of major importance was to provide specifications and to help design a modulated neutron initiator.

11.16 On the first of these problems, the effect of shock-heating on the course of the implosion, calculation of equations of state for DELETED DOE b(3) uranium were completed by April, and new IBM calculations of the DELETED DOE b(3) implosion thereafter included the effect of temperature. As a result efficiencies were decreased by a small amount, but less than had been anticipated.

11.17 On the question of stability of shocks, it was finally proven that plane shocks were stable, and the decay-rate of irregularities was found. In the absence of a complete theory for convergent shocks, it was nevertheless

possible to make rough estimates of the effects of instability

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11.18 In the design of the initiator, specifications were provided as to the initial neutron intensity required from the sudden mixing of polonium and beryllium. By April 1945 the design for the initiator had been frozen, the so-called urchin design (15.45).

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11.20 As the time of the Trinity test approached, the main effort of Group T-1 went into an attempt to explain certain discrepancies between the experimental data obtained from implosion studies in G Division and the results of the latest and most comprehensive IBM calculations. Densities measured by the betatron and RaLa methods were somewhat lower than the theoretical values. Measured shock velocities were also lower than theoretical values. Material velocities measured by the electric pin method were in agreement with theory, while those measured by the magnetic method were lower than predicted. A thorough canvassing of all the assumptions used in calculation, and examination of possible experimental errors, led finally to the conclusion that the theoretical calculations should be revised downward somewhat, but not by an

amount sufficient to alter the expected performance of the weapon very significantly.

Efficiency

11.21 During the period discussed in the present chapter the study of efficiencies, like that of other theoretical problems, moved from exploratory analysis intended to insure an essentially complete understanding of bomb physics, to final calculations of weapon design and performance, by the most reliable methods known. Efficiency calculations, in particular, carried the full responsibility of assuring the Laboratory that it was working toward an effective weapon, and of predicting as accurately as could be the efficiency of the bomb finally developed. In the nature of the case there could be no experimental verification of efficiency theory as a whole until the first test.

11.22 Several undertakings begun in the previous period were carried over and completed in the present period. The first of these was to examine carefully the effect of mixing between core and tamper, expected because of the Taylor instability at the interface.

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11.23 Another type of calculation considerably improved upon was the prediction of the initial multiplication rate for supercritical assemblies. Allowance for several groups of neutron velocities, in particular, introduced a transient time-dependence of this rate in the initial stages of multiplication. The comparison of this theory with experiments of Groups R-1 and G-1 was not satisfactory and required some re-examination of theory and experiments before good agreement was reached.

11.24 During this period, also, the qualitative understanding of the effect of radiation on the course of the explosion was brought to completion;

but reliable quantitative calculations remained impossible. Just before the Trinity test, therefore, the final efficiency prediction ignored this effect which, it was understood, might be responsible for a very much higher efficiency than that predicted.

11.25 As late as May, 1945, considerable worry was occasioned by the predetonation problem connected with the implosion assembly.

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11.26 Final efficiency calculations, published in the Theoretical Division Progress Report for June (LAMS 267), gave a prediction that the yield at the Trinity test would lie between 5,000 and 13,000 tons of TNT. The actual yield of the Trinity explosion was certainly in excess of this upper limit. One quite successful measurement made during the test was the initial multiplication rate of the bomb as it exploded. Using this value and omitting some pessimistic assumptions made in arriving at the yield range quoted above, recalculation gave a value near 17,000 tons. Both because of the uncertainties in measuring the yield and also because of the large theoretical uncertainty introduced by ignoring the effects of radiation, the close agreement between this figure and the "official" yield of 17,000 tons conceals several unsolved

problems. The first of these is the effect of radiation. The second is the proportion of the energy released converted into blast energy. Uncertainty about the latter relations makes it necessary to distinguish between the "nuclear" efficiency (fission energy released) and the "blast" efficiency, derived from the measurement of the blast wave. In view of the complexity of the efficiency problem and the unknown factors entering into it, the correspondence between theoretical and measured values was remarkably good.

11.27 There was somewhat less close agreement between the very successful result of the Trinity test and the subjective anticipations of many members of the Laboratory, who had by one argument or another prepared themselves against disappointing results. Shortly after the Trinity test, therefore, there was some discussion of possible unanticipated effects that might have accounted for the unexpectedly high yield. DOE b(3)

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Damage

11.28 Much more extensive investigation of the behavior and effects of a nuclear explosion were made during this period than had been possible before, tracing the history of the process from the initial expansion of the active material and tamper through the final stages. These investigations included the formation of the shock-wave in air, the radiation history of the early

stages of the explosion, the formation of the "ball of fire", the attenuation of the blast wave in air at greater distances, and the effects of blast and radiations on human beings and structures. Much of this information was of importance in making plans for the Trinity test. It was essential to know also the probable fate of plutonium and fission products in the ball of fire and the smoke cloud ascending out of it. These calculations, plus calculations of blast and radiation, were essential in planning experiments and observations at Trinity, and in planning for the protection of personnel. Theoretical studies of damage to structures and to personnel were of course made in anticipation of combat use. Extensive use in this connection was made of British data on damage to various kinds of structures caused by high explosive bombs. General responsibility for this work was given to Group T-7, with the advice and assistance of W. J. Penney.

Experiments

11.29 As in the earlier period reported (Ch. V), the consulting services of the Theoretical Division continued to occupy a considerable part of its time. Some of the more important lines of relationship have been discussed under the previous sections. Among the large number of neutron experiments on which the Division gave advice or performed computations may be mentioned the Gun Model experiment of Group R-1, the scattering experiments of R-3, the integral tamper experiments of R-1 and R-3, the multiplication experiments of R-1. For the Weapon Physics Division the theorists assisted with problems such as the design of RaLa experiments, the theory and analysis of magnetic pick-up data, and the focussing of x-rays for the x-ray method. Assistance was given, as before, in the design of various counters and detectors, and in calculating their efficiencies.

11.30 The most varied assistance was given to the operating groups engaged in the conduct of the Trinity experiment, all phases of which were under surveillance by the Theoretical Division which, as mentioned above, was responsible for preparing adequate order-of-magnitude calculations of the effects to be expected, and also for being sure that, in terms of these calculations, the experimental program was properly planned and coordinated.

11.31 In this place credit must be given to the computing Group, T-5, for its essential services in obtaining numerical solutions, required in most theoretical investigations.

Chapter XIII

F DIVISION

Introduction

13.1 As part of the administrative reorganization of the Laboratory, F Division was formed in September 1944, shortly after Fermi's arrival from Chicago. As Associate Director Fermi was given general responsibility for the theoretical and nuclear physics research of the Laboratory. As Division Leader of F Division he was given the directive to investigate potentially fruitful lines of development not included under the main program of the Laboratory. This responsibility included the Super in its theoretical and experimental aspects, and means of fission bomb assembly alternative to the gun and the implosion. Because of Fermi's previous association with pile development, the Water Boiler Group was also placed in this division. The last group in the division was added in February 1945, to do experimental work with the high power water boiler as a neutron source, and to prepare for the measurement of fission fragments at the Trinity test. The work of F Division in the Trinity test is reported in Chapter XVIII.

13.2 The group organization was as follows:

F-1.	The "Super" and General Theory	E. Teller
F-2.	The Water Boiler	L. D. P. King
F-3.	"Super" Experimentation	E. Bretscher
F-4.	Fission Studies	H. L. Anderson

The Super

13.3 During June of 1944 Teller's group had been separated from the Theoretical Physics Division and placed in an independent position, reporting to the Director. This separation was a recognition of the exploratory

character of this group's work as contrasted with that of the Theoretical Division generally, which had primarily responsibility for obtaining design data for fission bombs. Again in August 1944 Teller's group became the theoretical branch of the new F Division, created under Fermi.

13.4 Theoretical work on the Super from this time was without essential surprises. The analysis of the thermonuclear reaction became more quantitative and concrete. Increasing attention was given to the theory of detonation-mechanisms. Work reached its highest intensity in the spring of 1945 and continued for several months after the end of the war and the period covered by this report.

13.5 The detailed chronology and connections of these developments will not be traced here. There will be, rather, a qualitative account of the processes fundamental to the operation of a thermonuclear bomb, as finally understood. These processes are, in summary: the release of nuclear energy in high-temperature collisions, the transfer of energy from product particles to the medium, the loss of energy by radiation, the loss of energy because of the presence of low temperature radiation, the loss of energy through thermal conduction.

RELEASE OF ENERGY IN HIGH TEMPERATURE COLLISIONS

13.6 New measurements of the reactivity of deuterium with deuterons and tritons having the low energies of thermal motion were performed by Bretscher's group. (13.38). The new D-D data agreed with previous theoretical extrapolations from the old, high energy data. The low energy T-D reactions, however, turned out to have a considerably higher reactivity than even that anticipated from old measurements.

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13.7 The theoretical investigation showed that a steep rise in the rate of energy evolution can be expected with a rise in temperature.

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TRANSFER OF ENERGY FROM PRODUCT PARTICLES TO THE MEDIUM

13.8 The nuclear energy released in the reaction of a deuteron or triton with a deuteron is transferred into the kinetic energy of the product-particles. This energy must, in turn, be used to heat the deuteron medium to produce more reactions. The product-particles transfer their energy through collisions. In general the energy is "deposited" in the medium through a chain of collisions, during which the product-particles disperse themselves. Because of this dispersion the volume to be initially heated must be large enough to catch most of the energy deposits; otherwise the product-particles will escape from the system with too large a part of their energy, and the reaction will fail to be self-propagating.

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LOSS OF ENERGY BY RADIATION

13.9 The mechanism of radiation-loss has already been described. Since the loss rate at low temperatures exceeds the production rate but rises much less rapidly with temperature, there is a minimum temperature, called the "ideal ignition temperature", at which the energy evolution reaches equality with the Bremsstrahlung loss rate. The qualification "ideal" refers to the fact that only radiation losses are so far taken into account, and not, for instance, the losses accounted for by the escape of product particles from the system with part of their energy.

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LOSS OF ENERGY IN THE PRESENCE OF LOW TEMPERATURE RADIATION

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ENERGY LOSS THROUGH THERMAL CONDUCTION

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13.14 This completes the summary of the essential processes taking place in a thermonuclear bomb. Through their analysis some requirements to be fulfilled by any successful design were known. The conditions considered relate, however, only to the behavior of a given volume of reactant to which a given temperature is supplied.

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INITIATION

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DAMAGE

13.21 No account of the Super development at Los Alamos can be complete without some account of estimates of damage. It must be emphasized that these considerations are essentially qualitative. In fact with energies of the order contemplated, the effects of explosions begin to enter a new range, which may make necessary some account of meteorological and geological phenomena normally beyond human control. Under these circumstances accurate calculation is less important than a thorough canvassing of the possibilities.

The following account is highly tentative, both quantitatively and in degree of thoroughness.

13.22 The ten-million ton Super described above would not be the largest explosion seen on the Earth. Volcanic explosions and the collision of large meteorites such as the Arizona or Siberian have undoubtedly produced larger blast energies, perhaps a thousand or ten thousand times larger. On the other hand these explosions were very cool compared to a thermonuclear explosion, and correspondingly more familiar in their effects.

13.23 The blast effects from a ten-million-ton Super can be scaled up from the known damage at Hiroshima and Nagasaki. Taking the destroyed area from a ten-thousand-ton bomb to be ten square miles, the Super should produce equal blast destruction over a thousand-square-mile area. This would be more than enough to saturate the largest metropolitan areas.

13.24 More widespread ground damage would perhaps result from an explosion underground or underwater near a continental shelf. Since it is estimated that a severe earthquake produces energies of the same order as the Super, the surface effects might be comparable. To produce these effects would require ignition at a very great depth, of the order of several miles.

13.25 This bomb begins to reach the upper limit for blast destruction that is possible from detonation in air. Just as a fission bomb exploded in shallow water will have its radius of destruction in water limited by the depth at which it is exploded (14.21), so with a Super in the atmosphere. It "blows a hole" in the atmosphere, so that the maximum radius of destruction is comparable to the depth of the atmosphere.

13.26 Neutrons and gamma rays from the Super would not be a significant part of its damage; their intensity falls off more rapidly with

distance than the blast effects. Even at Hiroshima and Nagasaki they did not cause a large percentage of casualties. From a larger bomb their effects would be greater, but not proportionately greater.

13.27 The effects of visible radiation, on the other hand, fall off less rapidly than blast effects. This destruction can, in fact, be made directly proportional to the energy release. While blast damage can be increased a hundredfold, visible radiation damage can be increased a thousandfold. For the first purpose the bomb would be detonated about ten times higher than at Hiroshima and Nagasaki, for the second about thirty times higher. And the real point of the latter method is that there is no limit to the possibility of detonating larger bombs at higher altitudes. Thus a super which burned a ten-meter cube of deuterium at a height of three hundred miles would equal in effect a thousand "ordinary" supers detonated at ten-mile altitudes. In both cases the area of damage would be in the neighborhood of a million square miles. It should, of course, be emphasized that such a high altitude weapon is at the present time only a theoretical possibility.

13.28 It is difficult to estimate damage from visible radiation. In Hiroshima and Nagasaki the total effect was a composite of blast, gamma radiation and visible radiation. The last was sufficiently intense to ignite wooden structures over an area of a square mile or so. Casualties from visible radiation alone would be considerably smaller, because of the protecting effect of clothing and walls. Effects from a super would be comparable, and either more or less intense depending on the relative military importance of extensive versus intensive burning. The figures already given would correspond to an intensity about the same as that at Hiroshima and Nagasaki.

13.29 The most world-wide destruction could come from radioactive

poisons. It has been estimated that the detonation of 10,000 - 100,000 fission bombs would bring the radioactive content of the Earth's atmosphere to a dangerously high level. If a Super were designed with a U^{238} [DELETED] DOE b(3) catch its neutrons and add fission-energy to that of the thermonuclear reaction, it would require only in the neighborhood of 10 to 100 Supers of this type to produce an equivalent atmospheric radioactivity. Presumably Supers of this type would not be used in warfare for just this reason. Without the uranium [DELETED] DOE b(3) deuterium radioactive elements could be produced only by absorption; for example, carbon^{14} could be produced in the atmosphere; not, however, in dangerous amounts. Poisoning, moreover, would be obviated by detonation above the atmosphere, which is in any case the region in which the general destructive effects of the Super seem greatest.

Other Theoretical Topics

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13.34 Some time was spent on safety calculations for the K-25 diffusion plant, principally on estimations of critical assemblies of enriched uranium hexafluoride under various conditions and degrees of enrichment.

13.35 A topic of interest in connection with the Trinity test was the formation of chemical compounds in air by the nuclear explosion. Such compounds as oxides of nitrogen and ozone are poisonous, and the quantity produced had to be estimated. It was also anticipated that they would affect the radiation history of the explosion, which was to be examined spectrographically.

Deuterium and Tritium Reaction Cross Sections

13.36 It was stated above (13.6) that the low-energy cross section of the T-D reaction was found to be higher than extrapolation from high energy

data had indicated. This discovery, which considerably lowered the ignition temperature of T-D mixtures, was the result of work undertaken at the beginning of the period under review by Group F-3, the Super Experimentation Group.

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13.37 Since both the T-D and the D-D cross sections at low energies were known only by rather dubious extrapolation, it was planned to measure them simultaneously.

13.38 The first series of measurements was made with a small (50 kev) Cockcroft-Walton accelerator constructed for the purpose at Los Alamos. With this equipment experiments were carried out in the region from 15 to 50 kev. The quantity measured was the total number of disintegrations as a function of the bombarding energy, from which the reaction cross sections could be derived. In both cases the target used was made of heavy ice cooled with liquid nitrogen. The D-D reaction was produced by a deuterium ion beam, and the protons produced in the reaction measured. In the case of the T-D reaction the procedure was analogous, except that special precautions had to be taken to conserve the small amount of tritium available as an ion source. In this case the alpha particles from the reaction were counted.

13.39 The result of these measurements was that the extrapolated values of the D-D cross section were shown to be approximately correct. The tritium cross section, however, was very much larger than had been anticipated at energies of interest DELETED DELETED DOE b(3)

13.40 These measurements were later (after the end of the period under review) extended to the 100 kev region, using a larger accelerator constructed for the purpose.

A large amount of enriched uranium, surrounded by polythene, had been placed in a container to which water was being slowly admitted. The critical condition was reached sooner than expected, and before the water level could be sufficiently lowered the reaction became quite intense. No ill effects were felt by the men involved, although one lost a little of the hair on his head. The material was so radioactive for several days that experiments planned for those days had to be postponed.

15.11 Similar safety tests were made on models of the gun assembly. These tests were made because water immersion of the bomb might occur accidentally in transporting the bomb or in jettisoning it from aircraft. Immersion could also be thought of as the limiting case of wetting from other possible sources.

15.12 The number of tests made with U^{235} metal assemblies was much larger than those with Pu^{239}, since sufficient plutonium was available only rather late. The first critical assembly of the latter material, which was of a water solution of Pu^{239} with a beryllia tamper, was made in April 1945. By fabricating larger and larger spheres of plutonium and inserting these in a bomb mock-up, the critical mass in a bomb was determined.

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15.13 In April 1945 when G Division was given the definite responsibility of designing the pit assembly of the bomb, the "G Engineers", Morrison and Holloway, were taken for this work from the Critical Assemblies Group. The G Engineers worked with the design staffs of X and O Divisions in the final detailed design of the implosion bomb.

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15.14 At the request of the G Engineers the theorists made further calculations on the predetonation problem, and this reconsideration led to higher estimates of the probability of serious predetonation (11.25).

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Implosion Studies: The X-Ray Method

15.15 The X-raying of small spherical charges was developed in the Ordnance Division and was in successful use in August 1944 (7.70). At this time the small scale work was placed in X Division, and the G Division X-ray Group was formed to extend this method of implosion study to larger scale. In addition to this development work the G Group continued a number of service activities, such as the servicing and improvement of the X-ray tubes for the X Division work. Other demands made upon them included the radiography of explosive charges for the RaLa Group. Radiographic examination of the final weapon tamper was also a problem for this group near the end of this period but the work was done with radioactive sources of gamma rays rather than with X-rays.

15.16 In the early part of the new program the chief objective in the development work was to adapt X-ray techniques to large scale implosions (up to

200 pounds of high explosives). It was proposed actually to follow the course of the implosion by detecting the incidence of the X-rays as a function of time, using a grid of small Geiger counters. These counters were to be either of one or three millimeters in diameter, and disposed in the form of a cross in the X-ray shadow of the object. The principal aims of the projected program were (1) reliable action of the counters and (2) reduction of the amount of scattered radiation that would be recorded. These objectives were pursued relentlessly, but because of the great technical difficulties involved, with little real success. The program was dropped in March 1945. It had become clear that, although the difficulties might not be insurmountable, there was not sufficient justification for retaining the highly trained personnel required for this work. At this time also it had become clear that essentially the same type of information was obtainable by repeated exposures with the betatron (15.26 ff).

15.17 Although the development of the counters and their electronic circuits and the reduction of the scattered radiation were uncertain of success in the new X-ray program, preparation of a field site where the technique could be tested was completed by early fall 1944. This site was called P Site. The protection required for X-ray equipment near exploding charges was designed so that it would be useful in other X-ray experiments as well. As a preparation for the final use of the X-ray and counter technique, the problems of using the magnetic method (15.20) in conjunction with the X-ray method were solved at P. Site. The first combined X-ray and magnetic record was obtained in late January 1945. The technique was directly applicable to the combination of betatron and magnetic records (15.29).

15.18 For the most part the great usefulness of P Site was in providing for small scale X-ray experiments with photographic plate exposure. DELETED

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These experiments, as well as most of the small scale photography at

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P Site, were under the direction of Tuck [DELETED] [DELETED] [DELETED]

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15.19 As emphasis on lens design [DELETED] [DELETED] the flash X-ray photography was used in the study of the interaction jets formed at the intersection of detonation waves. These studies paralleled those of the X-ray section of the Implosion Studies Group X-1 (16.9 ff).

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From March on, therefore, the work of the X-ray Group at P Site was largely devoted to the study of various proposed initiator mechanisms.

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In April 1945 a second X-ray team was placed on the initiator problem. Altogether, a large amount of important experimental work on initiators was accomplished. The use of P Site for the initiator program branched out into various recovery experiments carried out there, and finally to the installation of the alpha counting experiment (15.44) there.

Implosion Studies: The Magnetic Method

15.20 By August 1944 the magnetic method had been established as a practical way of determining the velocity of the external metal surface of an imploding sphere (7.70). By integration the average compression could also be obtained. The development of the method was directed along three main lines: (1) the improvement of the instrumentation and adaption of the method to large charges with electric detonation; (2) cooperation with Bala, X-ray and betatron experiments to get coordinated records and (3) the development of new methods.

15.21 The first part of the program started with the construction of a

separate proving ground in the Pajarito Canyon (see Site Map). This was completed in December 1944. Meanwhile a great deal of work was done in the Laboratory in improving the circuits and developing shielding techniques. When the field work got under way it was found that the main problem was to protect the magnetic record against spurious signals caused by the electric detonators and by the static charges developed in the explosion. New results were obtained when it became possible to "purify" the magnetic records and interpret their details. It was found that several reflected shock waves from the metal core could be recognized. The intersection of detonation waves also produced reliable signals.

15.22 The magnetic techniques were adapted to larger charges, more detonation points, and finally to the electric detonation of lenses. The increase of surface velocity with number of detonation points was demonstrated in this way.

15.23 A unique property of the magnetic method was the fact that it was the only experimental method that could be applied to a full scale implosion assembly. The electric method (15.37ff) could be applied at full scale, but not to complete spheres. One of the chief objectives of the magnetic program was to prepare for the investigation of full scale shots. Unfortunately the method could not be used at Trinity because it was desirable to fire that shot with the same type of metal case as used with the bomb assembly, and this case made it impossible to obtain magnetic records.

15.24 As technical difficulties were surmounted the method was applied successfully at DELETED tamper diameters. At these scales the method was used alone as well as in coordination with the RaLa and Betatron methods. The timing results were particularly useful in these cooperative tests. As a method by itself its main value lay in following the dynamic sequence in the implosion and giving data as to the way this changes with increasing size of the implosion. DELETED DELETED DELETED

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15.25 Although the magnetic method rapidly developed into a widely used research tool in essentially its original form, it was widely recognized that this method was limited by the fact that

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Implosion Studies:: The Betatron

15.26 The use of the betatron as an instrument to study the implosion had been proposed earlier, but was not decided upon until the time of the discussions which led to the formation of G Division. For this work the 15 million volt betatron of the University of Illinois was obtained, after expert analysis of its capabilities for this work by its inventor, D. W. Kerst, and of the possible use of a vertical cloud chamber for recording by Neddermeyer. These analyses gave sufficient promise of success to justify undertaking the development of the method. Experimental work was begun in the early fall of 1944, on the performance (rise and burst times) of the betatron at Illinois and also on the refinement of shadow recording by means of flash photography of the cloud chamber.

15.27 Construction of the betatron site (K Site) was begun concurrently. As at the X-ray site, the test implosion was detonated between two closely spaced

bombproof buildings, one containing the high voltage gamma ray source, the other containing the cloud chamber and recording equipment. Equipment was protected from the blast by aluminum nose pieces over the exit and entry ports through which the radiation passed, and by shock-mounting all equipment which could be damaged by the shock wave. Construction and installation required until the first of 1945 for completion.

15.28 In the meantime the cloud chamber technique was improved by finding means for trapping the low energy tracks to obtain better definition of the image in the cloud chamber, and by an intricate and ingenious sequence circuit developed in the laboratory. This circuit had to correlate the firing of the explosive charge, the gamma ray burst, and the expansion and photographing of the cloud chamber.

15.29 By the time the first test shots had been fired [DELETED] [DELETED] [DELETED] the importance of results from the betatron had become crucial because of the likely abandonment of the counter X-ray method. The adaptation of the field installations, the electronic circuits and the cloud chamber to their special purposes proceeded so rapidly that by April 1945 a systematic study of compression under lens shots at [DELETED] scales was started. The results of the early work showed an unexpected irregularity, but nonetheless gave evidence of definite compression of the [DELETED] uranium core by an amount not very different from that predicted theoretically. By June, the spread of data had been reduced enough to provide valuable experimental information for the correction of the constants used in the theory of the bomb. Cooperative data provided by the magnetic method (15.20 ff) indicated that the spread in experimental results was possibly caused by variation in the behavior of the high explosive.

15.30 The betatron program was one of the few that maintained a single purpose and function from its inception to the production of final results. If

for this reason its history can be written briefly, the technical achievements and ultimate importance of this work are among the most impressive of the several such achievements at Los Alamos.

Implosion Studies: The RaLa Method

15.31 The RaLa program (7.74) resembles the betatron effort in that it was a single-purpose, more or less direct, adaptation of a known radiographic technique to the study of implosions. Both methods had to be adapted to microsecond time resolutions. For RaLa this meant the development of unprecedented performance with ionization chambers as well as unheard of sources of gamma radiation. As has been said elsewhere (17.52), the source of radioactivity was the radiobarium from fission products of the chain reacting pile. By the fall of 1944, the extraction of radiolanthanum had been put on a working basis. The production of sufficiently fast ionization chambers had also been achieved.

15.32 The RaLa firing program itself got under way in Bayo Canyon (see Site Map), October 14, 1944. Because of the lack of knowledge as to how serious the contamination would be after imploding a source which was the equivalent of many hundred grams of radium, the permanent installations were kept at a minimum for these first trials. Sealed army tanks were used as observation stations. The contamination danger appeared so conveniently small, however, that permanent bomb proofs were subsequently installed (November 1944).

15.33 The early shots were fired by multipoint, primacord systems and the results were correspondingly erratic.

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15.34 In February electric detonators were put into use and the quality of RaLa results immediately improved. In the course of the spring further refinements were made in the ionization chambers. Protection was provided against spurious signals. Provision was made for obtaining simultaneous magnetic records. As a result the significance of the results obtained was so improved that the RaLa method became the most important single experiment affecting the final design of the bomb. The principal advantage of the method was that analysis of the data gave an average of the compression as a function of time. This threw light on two of the most critical attributes of the system, namely, the duration and magnitude of maximum compression. A disadvantage of the method was that uranium had to be replaced by cadmium and full scale shots could not be made. Since uranium had too much gamma ray absorption, an IBM calculation had to be made for the RaLa model as well as the bomb model. If the RaLa calculation agreed with the experiment then it was assumed that the calculation for the actual bomb was probably also correct.

15.35 A second RaLa site was started in March 1945 in order to utilize the ever increasing amounts of activity available. The first high quality lenses produced were allocated to this work, beginning in April, so as to approach final design as rapidly as possible.

15.36 The RaLa program was relatively straightforward, but its success was possible only because of unsparing pains in the construction and testing of equipment, under almost assembly-line conditions of operation. Each shot involved the destruction of ionization chambers and electronic equipment that could not be removed from the neighborhood of the shot. Each new set of equipment had to be completely checked to be sure of proper operation on the single occasion that counted

Implosion Studies: The Electric Method

15.37 The principal technique of the electric method of investigating the implosion was that of recording electronically the electrical contacts formed

between the imploding sphere and prearranged wires. This is a well-established method of investigation but, as always in adapting old methods to implosion work, it was necessary to sharpen the time resolution and meet rather more serious interference with the circuits on the part of the explosive than had previously been encountered.

15.38 The development of the electric method was undertaken in August 1944. Although many possible applications of electronic circuits suggested themselves, the first effort was to make oscillographic recordings of the position of a plate as a function of time, when the plate was accelerated by a high explosive charge. This was done by merely spacing small pins at intervals differing by about a millimeter from the surface to be accelerated. The first successful results were obtained in early October 1944. The technique was then rapidly developed and refined, so that by the early part of 1945 quantitative data on the acceleration of plates was being obtained. The method was then adapted to the more severe implosion of partial spheres, and finally used on lens systems in which only one lens was omitted. Information was obtained on velocities of material at various depths in the core, and on shock-wave velocities. This information was particularly valuable in supplying the Theoretical Division with direct, quantitative data on which to test its conclusions and base its predictions for the implosion bomb.

15.39 Variations of the technique described above were studied but not developed as fully as the contact method. These included the condenser microphone and resistance wire methods. The use of tourmaline crystals for timing signals, as well as for possible pressure recording was pursued by the Initiator Group. In addition to the information, of general theoretical interest, on the properties of metals under compression, these methods were useful in many particular studies. Thus the Initiator Group was able to determine the pressure distribution in a detonation wave, and the Electric Method Group measured transit times relative to detonation times, uniformity of lens operation and the location and velocities of

spalls and jets. They also measured many velocities of interest in connection with initiator design, and the velocity of shock-operated jets formed in the thin crack between tamper halves.

15.40 Aside from its general usefulness for many research purposes of G Division, the Electric Method was--apart from the magnetic method--the only one which could be applied at very large scale. By June 1945, the technique was being applied regularly at large scale and to almost complete spheres of lens charges.

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Initiators

15.41 The Initiator Group differed from those discussed above in that it was primarily concerned with the development of a component of the bomb rather than with a particular research method.

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15.42 A proving ground was built in Sandia Canyon (see map) for this work. The nature of proof was not predetermined, however, and in any case could not be complete, because the performance requirements could be measured only by operation in the bomb itself. Many leads were followed, accordingly, in the attemp to simulate actual conditions as closely as possible and to learn as much as possible about the mechanisms that were supposed to make the various designs work.

15.43 The initiator program involved a great deal more than the attention of the Initiator Group. A large part of the problem was the procurement and radiochemical preparation of polonium. (17.38 ff) There was considerable theoretic investigation of proposed initiator mechanisms, and a large amount of experimental corroboration was produced by the X-ray, flash photography and electric methods. The function of the Initiator Group was to coordinate these researches with its own and with trends in design.

15.44 By February 1945 it was pretty well decided that the initiator should be of an (α,n) type using polonium and beryllium. Many designs were invented, and the work of selecting promising ones and testing them was started. All designs worked by some mechanism for mixing polonium and beryllium, previously kept separated by some α-absorbing material such as gold, under the impact of the incoming shock-wave. At this time the possibility of complete recovery of imploded spheres was discovered. The recovery of units with and without polonium in them formed an important part of the early work. Although the results thus obtained built up confidence in the feasibility of initiators, this work was superseded by studies of specific mechanisms.

15.45 The deadline for a decision on the feasibility of an initiator was met, with a favorable report, on May 1, 1945. At that time the decision was made to concentrate on the "urchin" design for production of a service unit.

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15.46 In the course of the month after May 1 the acceptance specifications and fabrication procedures were established and the first service unit was finished by the radiochemists early in June. (17.45) (Appendix 7, No.34)

15.47 The Initiator Group set up handling procedures in cooperation with the G Engineers and the Radiochemists for production, surveillance and recording the history of each unit. This plan had just been put in operation by the end of the wa

Electric Detonators

15.48 The need for a high degree of simultaneity in the multipoint detonation of the implosion had been realized from the beginning, as had the potential usefulness for this purpose of electric detonators. The early development of primacord branching systems, the investigation of timing errors associated with them, and the experimental and theoretical discovery of the crucial importance of such errors, is reviewed in 7.76 and 16.15 ff. Electric detonators were already under development by the beginning of the period reviewed, and during August 1944 this work was transferred to the new G Division.

15.49 The degree of perfection desired was, of course, not built into the commercial electric detonators, and the problem of simultaneously firing many such units had not been faced. This required the development of an adequate high voltage power supply and of a simultaneous switching device. The high voltage supply could be made from commercial units, and was simply a bank of high voltage condensers. The switch problem, acute at first, was met by straightforward developments which led to several designs adequate for experimental purposes. The switch finally developed for weapon use and the particular DELETED detonators

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used, were proved in X Division (16.58) But with a firing circuit adequate for experimental purposes it soon became apparent that there was a serious lack of simultaneity and source of failure in the detonators themselves.

15.50 Detonators of two types were studied, the bridge wire and spark gap types. Impetus for the study of spark gap detonators with lead azide came from England in the summer of 1944, where detonators of this sort were being fired with timing errors reduced to microseconds. The reduction of errors came from the use of powerful high voltage spark discharges. The use of similar high voltage energy sources with commercial bridge-wire detonators at Los Alamos also showed a comparable reduction of timing errors. It was wrongly assumed that even with powerful electric discharges only primary explosives -- i.e. those normally used for detonation of less sensitive explosives -- could be used. A contract was arranged with the Hercules Powder Company for the production of several types of experimental detonators, mostly loaded with lead azide.

15.51 Because of delays in manufacture, only a few batches of these detonators were received. In the meantime facilities for rapid loading of experimental detonators were developed at Los Alamos, and this local supply became the primary one.

15.52 The main path of detonator development was determined by another discovery at Los Alamos in the late summer of 1944. This was the fact that, with the high energies necessary to detonate primary explosives with small timing errors, PETN could also be detonated with comparable timing errors, and could not be detonated at all with lower energies. This was of great importance from the standpoint of safety, particularly safety in battle use, because it reduced the possibility of accidental detonation from such sources as accumulated static charges or leakage from low voltage energy sources in the bomb. The use of PETN detonators made it possible, among other things, to eliminate the use of "safety gates", mechanical separators between the detonator and the high explosive, which would

have been a most troublesome design problem had their use been necessary.

15.53 Many factors were found to affect the timing or the energy threshold of the PETN detonators: Mechanical factors, such as the length, diamete and composition of the bridge wire, its location in the detonator cavity and the shape of this cavity, electrical factors, such as the voltage and capacity of the energy source, impedance in the circuit, variations in resistance between detonato connected in parallel; the explosive, its density, particle size and crystal form. These latter factors were so important that careful control of the preparation and loading of detonators was necessary.

15.54 The criterion for acceptance was of course a small maximum time spread and percentage of failures. Tests were made by oscillographic methods and later by photographic observation, using the rotating mirror camera.

15.55 In the spring of 1945 the Detonator Group was burdened with the supervision of the preparation of thousands of detonators for field work in the implosion program. By the end of May the specifications for the combat service units had been completed, and responsibility for putting the units into service was taken by Group X-7 (16.58-9).

Photography

15.56 The Photographic and Optics Group, which before August 1944 had been a part of the Instrumentation Group of the Ordnance Division, was responsible in G Division for the development of optical instruments and for the operation of technical photographic facilities. As such it was partly a service group and partly an experimental group. It prepared photographic and spectrographic equipment for the Trinity test. Before that it had played a substantial part in the Wendover drop tests.

15.57 Besides procurement of photographic equipment and maintenance of a photographic stockroom, the Photographic Group designed and built cathode ray oscilloscope cameras, armored still cameras for various high explosives test sites,

an armored stereoscopic camera for the flash photography of imploding hemispheres (16.12) and a cloud chamber stereoscopic system for the betatron cloud chamber (15.28). The group built boresights and a photo velocity system for the 20 millimeter gun. It designed and developed the rotating prism and rotating mirror cameras(15.54). As with electronic, so with photographic recording of data, the laboratory was able to reach a high level of perfection in accurate high speed work. Much of this work stands to the credit of the Photographic Group.

Electronics

15.58 Early in September 1944, the Electronics Group was greatly expanded because of the very heavy demands placed on it by the Laboratory. At this time many types of equipment were in production. Among the standard items made were scalers, power supplies, discriminators and two types of amplifiers with rise times of 0.1 and 0.5 microseconds. Many new pieces of equipment were designed and built. A scaler with a resolving time of 0.5 microseconds per stage, amplifiers with less than 0.05 microseconds rise time, a ten-channel pulse height analyzer, and a ten-channel time analyzer were constructed. The group built most of the electronic equipment used on the betatron and much auxiliary equipment for the cyclotron, van de Graaffs and D-D sources. It designed and built new sweep circuits, delay circuits calibrating circuits and a host of other circuits needed by a laboratory as large and diversified as Los Alamos had become. If the above gives some indication of the variety of work carried out by the Electronics Group, its magnitude is indicated by the fact that the membership of the group averaged in the neighborhood of fifty. These ranged from wire men to designers of new equipment. The number of major construction items ranges over a thousand, and the number of service and repair items far beyond this figure, for the period covered.

15.59 The services of this group are not reflected directly in a single part of the weapons finally developed at Los Alamos and for this reason are likely to be slighted. But it is safe to say that without its services many of the expe

ments of G Division and the Laboratory would not have been done as well, they would have required more time, and the completion of the bomb itself would have been delayed.

"A" Process

Nitrates from X or W

↓ reduction with dilute HNO_3 and HI

Pu^{+++}

↓ $H_2C_2O_4$

$Pu_2(C_2O_4)_3, 9H_2O$

↓ oxidation with $NaBrO_3$ and HNO_3

PuO_2^{++}

↓

$NaPuO_2Ac_3$

↓ HNO_3

PuO_2^{++}

↓ ether extraction with NH_4NO_3 and HNO_3

PuO_2^{++}

↓ reduction with dilute HNO_3 and HI

Pu^{+++}

↓

$Pu_2(C_2O_4)_3, 9H_2O$

yield 95 per cent
supernatant 60 liters
16 - 24 hours run

"B" Process

Nitrates from X or W

↓ oxidation

PuO_2^{++}

↓ ether extraction $Ca(NO_3)_2$ and HNO_3

PuO_2^{++}

↓ reduction with dilute HNO_3 and HI

Pu^{+++}

↓ $H_2C_2O_4$

$Pu_2(C_2O_4)_3, 9H_2O$

yield near 100 per cent
supernatants 30 - 40 liter
10 - 11 hours run

Results of Trinity Experiments

13.29 To give some notion of the number and scope of the experiments done in connection with the Trinity test, the following summary is included. (See chart of location of Trinity experiments in appendix). There were six chief groups of experiments: 1. Implosion; 2. Energy release by nuclear measurements; 3. Damage, blast and shock; 4. General phenomena; 5. Radiation measurements and 6. Meteorology.

1. Implosion experiments included:
   a. Detonator asimultaneity measured with detonation wave-operated switches and fast scopes. These records were fogged by gamma rays.
   b. Shock wave transmission time measured by recording on a fast scope the interval from the firing of the detonators to the nuclear explosion. This experiment gave a result [DELETED] in exact accord with predictions.
   c. The multiplication factor (a) measurement was done by three methods - with electron multiplier chambers and a time expander; by the two chamber method; and with a single coaxial chamber, coaxial transformers and a direct deflection high speed oscillograph. [DELETED] [DELETED] [DELETED]

DOE b(3)

DOE b(3)

2. The calculation of energy release by nuclear measurements included:
   a. Delayed gamma rays measured by ionization chambers, multiple amplifiers, and Heiland recorders from both ground and balloon sites.

b. Delayed neutron measurements done in three ways - by the use of a cellophane catcher and U^{235} plates both on the ground and airborne, by the use of gold foil detectors to give an integrated flux, and by the use of sulphur threshold detectors. For the cellophane catcher method a record was obtained from the 600 meter station which showed an energy release consistent with the H. Anderson figure (c. below). With the gold foil method the number of neutrons per square centimeter per unit logarithmic energy interval was measured at 7 stations ranging from 300 to 1000 meters from the explosion. Of the sulphur threshold detectors only 2 of the 8 units used were recovered and these gave the neutron flux for energies of 3 Mev at 200 meters.

c. The conversion of plutonium to fission products, measured by determining the ratio of fission products to Pu, gave a result DELETED DELETED equivalent to 18,600 tons of TNT. An attempt to collect fission products and plutonium on filters from planes at high altitude from the dust of the shot after it circled the world gave no results, although later some indications were obtained after the Hiroshima explosion by this method.

DOE b(3)

3. Damage, blast and shock experiments were divided into three groups: a. Blast, b. Earth shock and c. Ignition of structural materials.

a. Blast measurements included:

(1) Quartz piezo gauges - these gave no records since the traces were thrown off scale by radiation effects.

(2) Condenser gauges of the California Institute of Technology type were located from 3-19 [illegible] but no

records were obtained because the shot had to be fired when the planes were out of position.

(3) The excess velocity of the shock wave in relation to sound velocity was measured with a moving coil loudspeaker pick-up, by the optical method with blast-operated switches and torpex flash bombs and by the Schlieren method. By the moving coil loudspeaker method the velocity of sound was obtained for a small charge and then the excess velocity for the bomb; this measurement gave a yield of 10,000 tons and proved to be one of the most successful blast measuring methods.

(4) Peak pressure measurements were done with spring loaded piston gauges at an intermediate pressure range of from 2.5 pounds to 10 pounds per square inch, with the same kind of gauges above ground and in slit trenches at a pressure range of from 20 to 150 pounds per square inch, with crusher type gauges and with aluminum diaphragm "box" gauges at a range of from 1 to 6 pounds. The first of these methods gave blast pressure values which were low compared to all other methods, the crusher type gauges gave the highest pressure range and the "box" gauges gave a TNT equivalent to 9900 ± 1000 tons. This last method was found to be inexpensive and reliable.

(5) Remote pressure barograph recorders gave results consistent with 10,000 tons. These were necessary for legal reasons.

(6) Impulse gauges - mechanically recording piston liquid [illegible] orifice gauges - also gave results consistent with [illegible] tons.

(7) Mass velocity measurements were made by viewing with Fastax cameras suspended primacord and magnesium flash powder.

(8) Shock wave expansion measurements were made with Fastax cameras at 900 yard stations and gave a total yield of 19,000 tons.

b. Earth shock measurements included:

(1) Geophone measurements with velocity-type moving coil strong motion geophones gave 7000 tons after extrapolation from a small charge and 100 ton data.

(2) Seismograph measurements done with Leet 3-component strong motion displacement seismographs gave results of approximately 15,000 tons. These were necessary for legal reasons.

(3) Permanent earth displacement measurements using steel stakes for level and vertical displacements gave results of 10,000 ± 5000 tons.

(4) Remote seismographic observations at Tucson, El Paso and Denver showed no effect at these distances.

c. The ignition of structural materials was observed using roofing materials, wood and excelsior on stakes. Observations showed that the risk of fire produced by radiant energy is small for distances greater than 3200 feet. The risk of fire from direct radiation was likely to be much less than the risk of fire from stoves etc. at the time of the explosion. These conclusions were confirmed at Hiroshima and Nagasaki.

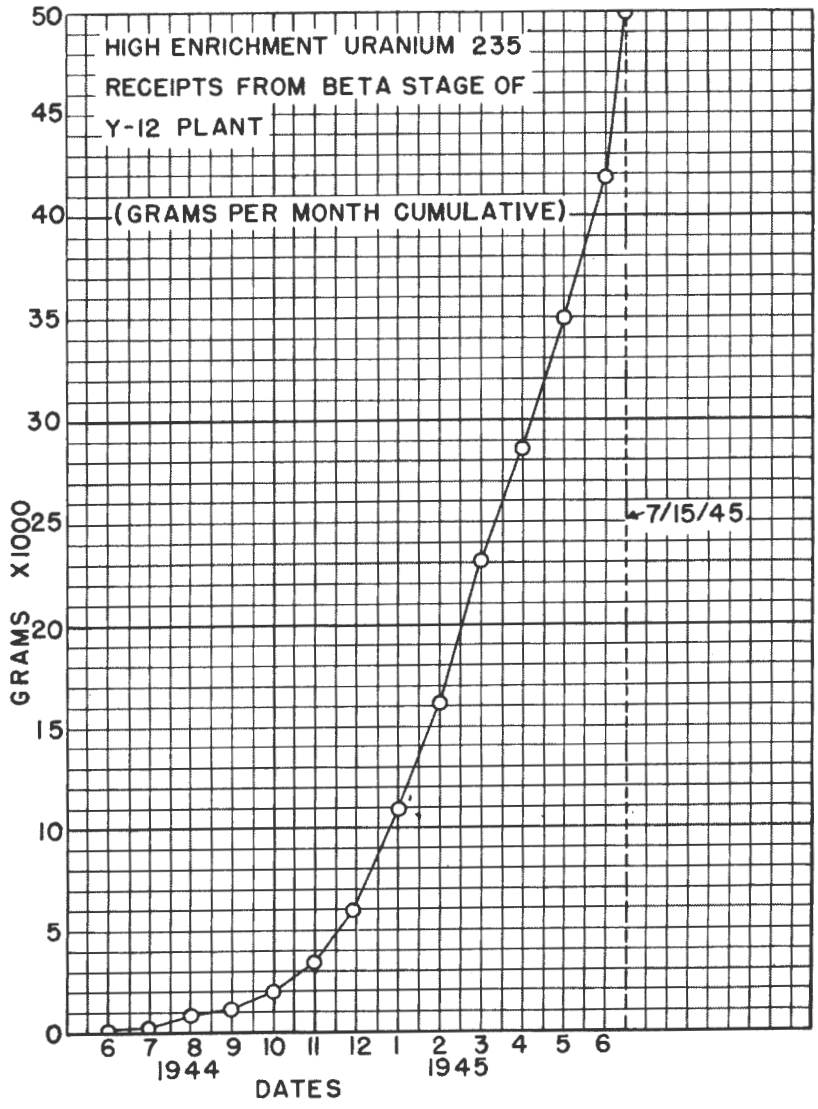
4. The study of general phenomena consisted chiefly of photographic studies of the ball of fire and the column of blast cloud effects. This group of

Graph Number 12

High Enrichment Uranium 235 Receipts from Beta Stage of Y-12 Plant

Cumulative total of U 235 received up to date of Trinity test. This represents all highly enriched U 235 produced by the District. Such material was shipped after the final processing done in the beta stage of the Y-12 plant at Oak Ridge. Enrichment of U 235 in tubealloy increased from 63% to 89%.

Information was obtained from records of receipts in Director's Office, now filed with the Quantity Control Section of the Chemistry and Metallurgy Division.


HIGH ENRICHMENT URANIUM 235
RECEIPTS FROM BETA STAGE OF
Y-12 PLANT
(GRAMS PER MONTH CUMULATIVE)
7/15/45
GRAMS X1000
0
5
10
15
20
25
30
35
40
45
50
6 7 8 9 10 11 12 1 2 3 4 5 6
1944
1945
DATES

Graph Number 13

Plutonium (Pu 239) Receipts - Clinton and Hanford

Cumulative total of Pu 239 receipts from Clinton and from Hanford. Clinton production very small, increasing slowly until it ended in February 1945. Hanford startup was in September 1944 and first material was received from there in February 1945.

Information was obtained from records of receipts in Director's Office, now filed with the Quantity Control Section of the Chemistry and Metallurgy Division.

(α,n) reaction

Any nuclear reaction in which an alpha particle (helium nucleus) is absorbed by a nucleus, with subsequent emission of a neutron.

Autocatalytic Assembly

Any method of assembling super-critical amounts of nuclear explosive, in which the initial stages of the explosion are made to assist the further assembly of the explosive, e.g., by expulsion or compression of neutron absorbers placed in the active material.

Baratol

A castable explosive mixture of barium nitrate and TNT.

Baronal

A castable explosive mixture of barium nitrate, TNT and aluminum.

Betatron

Induction electron accelerator for generating electron beams of very great energies.

Branching ratio

The ratio of the capture cross-section to the fission cross section.

Cockcroft-Walton Accelerator

An accelerator using voltage multiplication of the rectified output of a high voltage transformer to obtain a high potential.

Composition B

A castable explosive mixture containing RDX, TNT, and wax in the proportion 60/40/1.

Critical Mass

That amount of fissionable material which, under the particular conditions, will produce fission neutrons at a rate just equal to the rate at which they are lost by absorption (without fission) or diffusion out of the mass.

Tamped Critical Mass

The critical mass when the active material is surrounded by a tamper.

Critical Radius

The radius of a spherical arrangement of fissionable material equal to one critical mass under existing conditions.

Cross-Section

A quantitative measure of the probability per particle of the occurrence of a given nuclear reaction. It is defined as the number of nuclear reactions of a given type that occur, divided by the number of target nuclei per square centimeter and by the number of incident particles.

Absorption Cross-Section

The cross-section for the absorption of a neutron by a given nucleus.

Capture Cross-Section

The cross-section for the (n,γ) reaction, in which a neutron is absorbed by a nucleus, with subsequent emission of gamma radiation.

Fission Cross-Section

The cross-section for the absorption of a neutron, followed by fission.

Scattering Cross-Section

The cross-section for the scattering of a neutron by the nuclei of some target material. Since scattering is a quantitative matter, the definition is incomplete. The differential scattering cross-section is the cross-section for scattering at an angle between θ and $\theta + d\theta$. The transport cross-section is an average or integral scattering cross-section, so defined as to give the average scattering in the forward direction:

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$$\sigma_T = 2\pi \int_0^{\pi} (1 - \sin\theta)\, \sigma_s(\theta) \sin\theta \, d\theta$$

where $\sigma_s(\theta)$ is the differential scattering cross-section defined above.

Cyclotron

Magnetic resonance accelerator, used in investigating atomic structures.

D(d,n) reaction

The nuclear reaction produced by bombarding deuterons with deuterons, producing high energy neutrons.

D-D Source

The above reaction used as a source of high energy neutrons. At Los Alamos, the Cockcroft-Walton accelerator was principally used for this purpose.

Deuterium

Heavy hydrogen, D_2 or H_2^2, the hydrogen isotope of mass two.

Deuteron

A nucleus of deuterium or heavy hydrogen.

Electron Volt

An electron volt is the energy acquired by an electron falling through a potential of one volt. One electron volt is about 1.6×10^{-12} ergs. In thermodynamic units, one electron volt corresponds to a temperature of about 12,000 degrees absolute. Thus a fortieth of a volt per particle corresponds to "room temperature". Energies of this order are called "thermal". One million electron volts corresponded to a temperature of 1.2×10^{10} degrees absolute.

Fission Spectrum

The spectrum, or energy-distribution, of neutrons emitted in the fission process.

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Inelastic Scattering

The scattering of neutrons in which energy is lost to excitation of target nuclei.

Li(p,n) reaction

The nuclear reaction in which neutrons are produced by bombardment of lithium by protons.

Neutron Number

The number of neutrons emitted per fission. This number is statistically variable; the expression refers therefore to the average number per fission.

(n,γ) reaction

A nuclear reaction in which a neutron is captured by a nucleus, with subsequent emission of gamma radiation.

PETN

Pentaerythritol tetranitrate.

RDX

Cyclotrimethylenetrinitramine.

Thermo-Nuclear reaction

A mass nuclear reaction induced by thermal agitation of the reactant nuclei. The reaction is self-sustaining if the energy release is sufficient to counter balance the energy losses that may be involved.

Tamper

A neutron reflector placed around a mass of fissionable material to decrease the neutron loss rate.

Taylor Instability

A hydrodynamical principle which states that when a light material pushes against a heavy one, the interface between them is unstable, and that when a heavy material pushes against a light one, the interface is stable.

Tritium

The hydrogen isotope of mass three. This isotope was discovered in the Cavendish Laboratory by Oliphant in 1934. It was there produced by deuterium-deuterium bombardment. Tritium is a radioactive gas with a half-life of about twenty years, and therefore does not occur in nature.

Triton

A nucleus of tritium.

Thermal Neutrons

Neutrons of thermal energy - see Electron Volt.

T-D reaction

The nuclear reaction of tritons with deuterons.

Torpex

A castable explosive mixture of RDX, TNT and aluminum.

Van de Graaff Generator

An accelerator using the electrostatic charge collected on a mechanically driven belt to obtain a high potential.

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Manhattan District History

Book II - Gaseous Diffusion [K-25] Project

Vol. I - General Features

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 1 - GENERAL FEATURES

RESTRICTED DATA

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FOREWORD

This introductory volume presents a general discussion of the main features of the Gaseous Diffusion (K-25) Project. The purpose of the Project, authorization, theoretical foundations, preliminary planning, safety and security aspects, costs, and administrative organization are treated, and a brief overall description is given, with an indication of scope and magnitude, as well as a statement of problems posed by the decision to utilize the method of gaseous diffusion. The various aspects, as listed below, are dealt with briefly. In general, when greater detail is desired, reference should be made to succeeding volumes of Book II as follows:

Volume 2 - Research
Volume 3 - Design
Volume 4 - Construction
Volume 5 - Operation

Activities described in Volume 1 extend from the earliest OSRD contracts, negotiated in July 1941, for the study of the diffusion process, to 31 December 1946, at which time all basic phases of the K-25 program of research, design, and construction had been effectively completed, the gaseous diffusion plant existed as an operating entity, and administrative responsibility passed from the Manhattan District to the United States Atomic Energy Commission. The term, "K-25 Project" is used throughout in the broad sense, and is synonymous with "Gaseous Diffusion Project". The K-27 plant addition is viewed as a supplementary portion of the K-25 process plant. No new basic principles are involved in K-27, and its discussion is interlooked with that of the original phases of the Project throughout the course of Book II.

SUMMARY

1. Introduction. - The goal of the Gaseous Diffusion (K-25) Project was the large scale, multi-stage separation of Uranium-235 from the more abundant non-fissionable Uranium-238 by utilization of the principle of molecular effusion. The complete novelty, both of the manufacturing process, and of the process material, made necessary a major program of fundamental research, development, engineering, design, construction, and operation, involving a large number of university and industrial contractors. Basic authorization was obtained from the President. With the general approval of the S-1 Committee of the Office of Scientific Research and Development (OSRD), and the Military Policy Committee, Major General L. R. Groves directed the general policies under which the Manhattan District carried on the work.

2. Basic Theory. - In 1938 O. Hahn and F. Strassmann discovered the phenomenon of nuclear fission in uranium. It was subsequently realized that the fission reaction was due to the uranium isotope of atomic weight 235, and that the reaction could probably be made to sustain itself as a chain reaction with the rapid release of tremendous quantities of energy. The problem was therefore presented of concentrating Uranium-235, which exists in natural uranium only to the extent of 0.714 per cent. The task is complicated because of the small difference in the atomic masses of U-235 and U-238, which difference must form the basis of the operating process. The method of gaseous diffusion is based upon the experimental finding of Thomas Graham in 1829 that the rate of effusion of gases through small apertures is inversely pro-

portional to their molecular weights. The only known feasible working substance for the process was uranium hexafluoride, UF_6, which can be easily volatilized. The process equipment installed at K-25 consists of a lengthy series or "cascade" of diffusion stages. The "converter" of each stage is subdivided into a cooler and "diffuser". The diffuser is a tank-like piece of equipment which encloses the "barrier". The barrier is the heart of the process, and consists of a thin, porous, metallic membrane containing billions of submicroscopic openings per square inch. The stage "B pump" supplies the converter continuously with undiffused gas from the stage above, mixed with diffused gas from the stage below. The cooler removes the heat of pumping and maintains a constant operating temperature. Conditions are so arranged that half of the gas fed to the converter diffuses through the barrier, becoming slightly enriched in concentration of the lighter component in accordance with Graham's Law, and is delivered by the stage "A pump" to the next higher stage. The remaining half leaves the converter, passes through the control valve, which maintains a constant converter operating pressure, and enters the suction of the next lower stage"B pump." Product material is withdrawn from the "top" of the cascade. Depleted waste leaves at the "bottom".

3. Planning of the Project. - In July 1941, OSRD contract OEMsr-106 was awarded to Columbia University, providing for investigation of the method of gaseous diffusion as applied to uranium isotope separation. Contract OEMsr-406 was next awarded to the M. W. Kellogg Company for further experimental and engineering investigation. After the preliminary production plant program had been reviewed by the OSRD S-1

Executive Committee and the Reassessment and Reviewing Committee, it was decided to construct a 4600 stage plant to produce 1 kilogram per day of U-235 at a concentration of 90 per cent. Arrangements for the work were concluded in secret letter contract W-7405-eng-23 awarded to the M. W. Kellogg Company on 14 December 1942. For security and accounting reasons, Kellogg created a totally-owned subsidiary, The Kellex Corporation, which was to be wholly devoted to the K-25 undertaking. Fundamental research was carried on at the SAM Laboratories of Columbia University under OSRD contracts OEMsr-106 and OEMsr-412, and, after 1 May 1943, under Manhattan District contract W-7405-eng-50. On 1 February 1945, responsibility for the SAM Laboratories was transferred to the Carbide and Carbon Chemicals Corporation under a modification of contract W-7405-eng-26. The Kellex contract W-7405-eng-23 also called for extensive research and development, as well as stipulating that that corporation have overall responsibility for planning, engineering, design, and development of the Project. A number of specific phases of the research program were assigned to various other laboratories as subcontractors. A large number of additional firms participated in the immense design and engineering program, under general Kellex supervision. British assistance was also obtained on various theoretical and design problems. After a thorough review of all phases of the Project from the standpoint of cost, completion dates, performance, and capabilities of possible plants, it was decided on 18 August 1943 to construct a plant to produce material at an isotopic concentration of 36.6 per cent U-235, and on 31 March 1945 the "K-27 Plant", a side feed addition plant, was authorized, in order to increase the production capacity of K-25.

Diffusion plant construction was accomplished principally by the J. A. Jones Construction Company (contract W-7421-eng-11), and Ford, Bacon, and Davis, Inc. (contract W-7407-eng-19), each under the supervision of Kellex, and each assisted by numerous subcontractors. Operated principally by the Carbide and Carbon Chemicals Corporation under contract W-7405-eng-26, the plant has been in production since March 1945.

4. Description of the Project. - The K-25 production plant is located at the northwest corner of the Clinton Engineer Works military reservation. The process area includes the main cascade of 2892 stages, housed in a series of 51 contiguous buildings arranged to form a single large "U"-shaped structure. Each building is subdivided into from three to fourteen six-stage "cells" which are the smallest individually operable units. Auxiliary facilities include systems for feed purification, purging, surge and waste handling, process gas recovery, and product removal. Service installations are also provided for maintenance facilities, and for supplying compressed air, specially dried air, cooling water, and special coolant, in accordance with process requirements. The conditioning area includes principally the conditioning building, in which a large number of cleaning, fluorinating, and maintenance operations are carried on. A sizeable florine generation plant is also located within this area, together with a disposal unit for spent conditioning gas, a nitrogen vaporization system, and a 270,000 pound per hour low pressure steam plant; The power plant area includes a boiler house for three 750,000 pound per hour coal-fired units designed to produce steam at 1325 pounds per square inch and 935°F, a turbine room for 14 turbo-generators with a combined rating

of 238,000 KW, a storage yard for 250,000 tons of coal, and suitable switch house and pump house facilities. The administration area includes miscellaneous office buildings, laboratories, station houses, a cafeteria, a dispensary, and a laundry. The K-27 Area is a structurally separate annex to the main process area, consisting of a 540-stage cascade complete with auxiliary facilities, and so connected with the main buildings as to form a "cascade of cascades". Sometimes referred to as "the largest physico-chemical process in the world", the K-25 plant represents the fruition of a research, development, design, and manufacturing program which was spread throughout the nation. The greater plant area encompasses some 5000 acres. The cascade "U" is one mile in perimeter and one quarter mile across. The size of the installation, which had required 60,000 carloads of equipment and supplies as of 1 January 1946, is typified by the following: the plant contains 7,500,000 square feet of geometric barrier area, 8,700 process and coolant pumps, 100 miles of process piping, 130,000 specially engineered instruments, and 500,000 valves. Auxiliary facilities include one of the largest dry air installations ever constructed and a 170,000,000 gallon per day cooling water plant. The power plant is the largest steam-electric station ever constructed in a single operation, and a 200,000 gallon plant inventory is maintained of specially developed process coolant.

5. Major Problems. - A host of problems of unparalleled scope and complexity were inherent in the K-25 program. Outstanding amoung these were the evolution, development, and large scale production of barrier, a totally novel and highly specialized material. DELETED DOE b(3)

SECTION 2 - BASIC THEORY

2-1. Nuclear Fission. - With the momentous discovery by the German scientists, O. Hahn and F. Strassmann, in 1938, of the phenomenon of nuclear fission in uranium, a turning point in the course of modern physics was reached. The effect was one in which the element uranium was converted or transmuted into different elements, mass was converted into energy according to the predictions of Albert Einstein, new elements of transuranic atomic numbers were synthesized, and a tremendous reservoir of hitherto unleashed power was uncovered. With the subsequent realization that the breaking up of a uranium atom was initiated under proper conditions by the impact of a neutron, and further that several neutrons were released at high speed among the fission products, it was realized that this vital reaction might be made to sustain itself as a chain reaction. In other words, the conversion of part of the mass of a nucleus into energy could be multiplied billions of times within a very small fraction of a second. The fission phenomenon was subsequently shown to be due to the Uranium-235 isotope, and scientists turned their attention to the study of methods for separating this isotope from the more abundant Uranium-238.

2-2. Concentration of Uranium-235. - The element uranium exists naturally in the form of various compounds all of which contain the metal as U-238 - 99.28 per cent, U-235 - 0.714 per cent, and U-234 - 0.006 per cent. This third component, present in such a small amount, will be disregarded in further discussions, and the concentration problem may be visualized as one of separating U-235 from U-238. The

goal of the Manhattan District was to make available for military use the atomic energy released as a product of the fission reaction. The scope of the K-25 Project includes the enhancement on a large scale of the isotopic concentration of U-235 in uranium by means of the process of Gaseous Diffusion.

a. Separation of Isotopes. - The task of separating isotopes is well known to be complicated by the very nature of the problem. Thus isotopes of an element are identical as far as atomic number, and therefore chemical properties, are concerned. The distinction is one of structure and weight of the nucleus. Attempts at separation must be based upon differences in atomic weight. Methods employed must be physical rather than chemical, and further, they must make use of a difference between isotopes which is very slight; that is, the atomic weights of elements ordinarily differ by only a small number of mass units. The problems are particularly difficult in the case of uranium, which is the heaviest of all atoms in the classical periodic table. Thus a difference of three mass units between the atom of U-235 and that of U-238 amounts to only 3 parts in 238 (using the more abundant isotope as a basis for calculation) or 1.3 per cent. Slight as this difference is, it is significant, and within the Manhattan District, the separation has been effected by means of Thermal Diffusion (Book VI), by the Electromagnetic Method (Book V), and by the Gaseous Diffusion Method, which is the object of the K-25 Project.

b. Gaseous Diffusion.- A more accurate designation would be "molecular effusion" since the method is based upon the effect noted by Thomas Graham in 1829 wherein molecules in the gaseous state

tend to flow or "effuse" through narrow apertures at rates which under given conditions of temperature and pressure, are inversely proportional to the square root of the density or molecular weight. Thus, if a mixture of gases is confined within a container possessing a small opening, the lighter molecules will tend to escape more rapidly than the heavier ones, and a means is available for separating molecules according to mass. It is important to note that the size of the aperture must be of the same order of magnitude as the distance travelled by individual molecules between collisions with one another. Larger openings would permit ordinary "viscous" flow of the fluid mass without any separative effect.

2-3. Application of Theory.

a. Process Material. - Elemental uranium is a dense, heavy metal. The process calls for a gaseous process material, and the first requirement is therefore to obtain a compound of uranium in such form that it will be susceptible to processing by this method. As will appear in more detailed discussion (Vol. 2), the material, uranium hexafluoride (UF_6), presented itself, not without a series of important disadvantages, but nevertheless as the only known uranium-containing substance which could be handled in the gaseous state. Since the atomic weight of fluorine is 19, the molecular weight of $U^{235}F_6$ is 349, and the molecular weight of $U^{238}F_6$ is 352. It is important and fortunate that the situation is not complicated by variation in the atomic weight of fluorine, i.e., fluorine possesses no isotopes of its own. Thus the difference of three mass units between the atoms of U-235 and U-238 results in a difference of three mass units between the molecules of $U^{235}F_6$ and $U^{238}F_6$. Having chosen UF_6 as the working substance, how-

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MANHATTAN DISTRICT HISTORY

BOOK II - GASEOUS DIFFUSION (K-25) PROJECT

VOLUME 2 - RESEARCH

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	b. Scope of Research Commitments	2.2
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	b. Scope of Research Commitments	2.2
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	b. Scope of Work	2.3
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	(2) Production	4.15
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	d. DELETED	DOE b(3)
	e. DA Barrier	4.19
	(1) Procedure	4.19
	(2) Production	4.20
	DELETED	DOE b(3)
	f. WB Barrier	4.27
	(1) Procedure	4.29

[redacted]

designated by γ, was generally adopted throughout the Project for correlating barrier porosities. Further studies showed that the permeability of barrier is made up of two parts. One part (γ_o) is nearly independent of the gas used, and the test conditions of pressure and temperature. The second part is definitely a function of these variables. Thus, it was found that when observed permeability was plotted against "pressure sum" (fore pressure plus back pressure), a nearly straight line was obtained which could be represented by the equation:

$$\gamma = \gamma_o [1 + S(P_i + P_o)]$$

in which:

γ = permeability
Pi = fore pressure
Po = back pressure
γ_o = extrapolated value of permeability at zero pressure sum
S = the "slope factor"

The porosity properties of a barrier can be specified by giving values for γ_o and S.

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b(3)

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Barrier Type	γ_{16}	S
WB TL WL	DELETED	

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Permeability is dependent upon the operating pressure, increasing in magnitude as the difference between fore pressure and back pressure is increased. Permeability is also a function of barrier structure, increasing both with the number and size of the holes. A barrier of a certain permeability with a large number of fine apertures will show a greater separation factor than one with a smaller number of larger holes. It is necessary to specify both upper and lower limits for permeability, since if the permeability rises above the upper limit, or falls below the lower limit chosen for plant design, process pump efficiency decreases. Process pumps become unstable if their intake falls below a specified limit, and as permeability increases, either the horsepower of the process pumps must increase, or the total pressure of the plant must decrease.

b. Chemical Properties.

(1) Plugging Characteristics. - The barrier must be chemically inert to uranium hexafluoride, a very aggressive substance. Reaction of the barrier material with process gas can lead to serious reduction in permeability by growth of reaction products within the pores. Moreover, corrosion at other points in the process system can form solid products which may lodge in the apertures and produce the same result. Since six months was considered to be the minimum allowable life from the point of view of replacement and plant maintenance, a tolerable plugging rate for barrier was set at 0.16 per cent per day.

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/ Some work on the development of production methods was also done by Sam Tour, Inc. under a Kellex subcontract.

(2) Powder Nickel Barriers. -

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DOE b(3)

DELETED

DOE b(3)

This work was started under OSRD contract OEMsr-1125 (App. D19), and continued under contract W-7405-eng-142 (App. D20).

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DOE b(3)

(3)

Samples examined by Kellex personnel toward the end of that year showed good process properties and fair mechanical strength.

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On 1 September 1944, Kellex personnel and the pilot plant formerly located in the Nash Building were transferred to the SAM Laboratories. On 1 January 1945, the Schermerhorn DA barrier pilot plant was dismantled. The major part of the research had been accomplished, and from then on, attention was centered on another type of barrier. In the main K-25 cascade, plain DA barrier has been installed in 1962 stages.

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f. NB Barrier. - An account has been given, of the

powdered nickel barrier as studied at the Bell Telephone Laboratories and at the SAM Laboratories, first by Columbia and later by Carbide.

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Its separating efficiency was the highest observed in the porosity range of interest, both separating efficiency and porosity being readily controllable and reproducible.

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In January 1945, production was started by Linde and continued through March 1946 at which time the barrier plant was placed in standby condition.

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In order to establish the feasibility of producing the Y tubes in volume, the A. S. Campbell Company undertook a program of research and development.

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4-5. Powdered Nickel. -

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Eventually, two other varieties were shown to be suitable. One called powder B, or "Virginia" powder, was made by the International Nickel Company at Huntington, West Virginia, and by the Metals Disintegrating Company at Elisabeth, New Jersey; the other,

called C or "Elgin" powder, was made at the Elizabeth plant from nickel oxide obtained from the Linde Air Products Company at Tonawanda, New York.

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Subsequently, another nickel powder, called D powder, was developed and produced by Linde using an improved process which greatly increased the production rate.

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The product possessed the advantages of a continuous manufacturing process, it required only a short furnacing time, and it employed the previously unsatisfactory domestic powders which were readily available.

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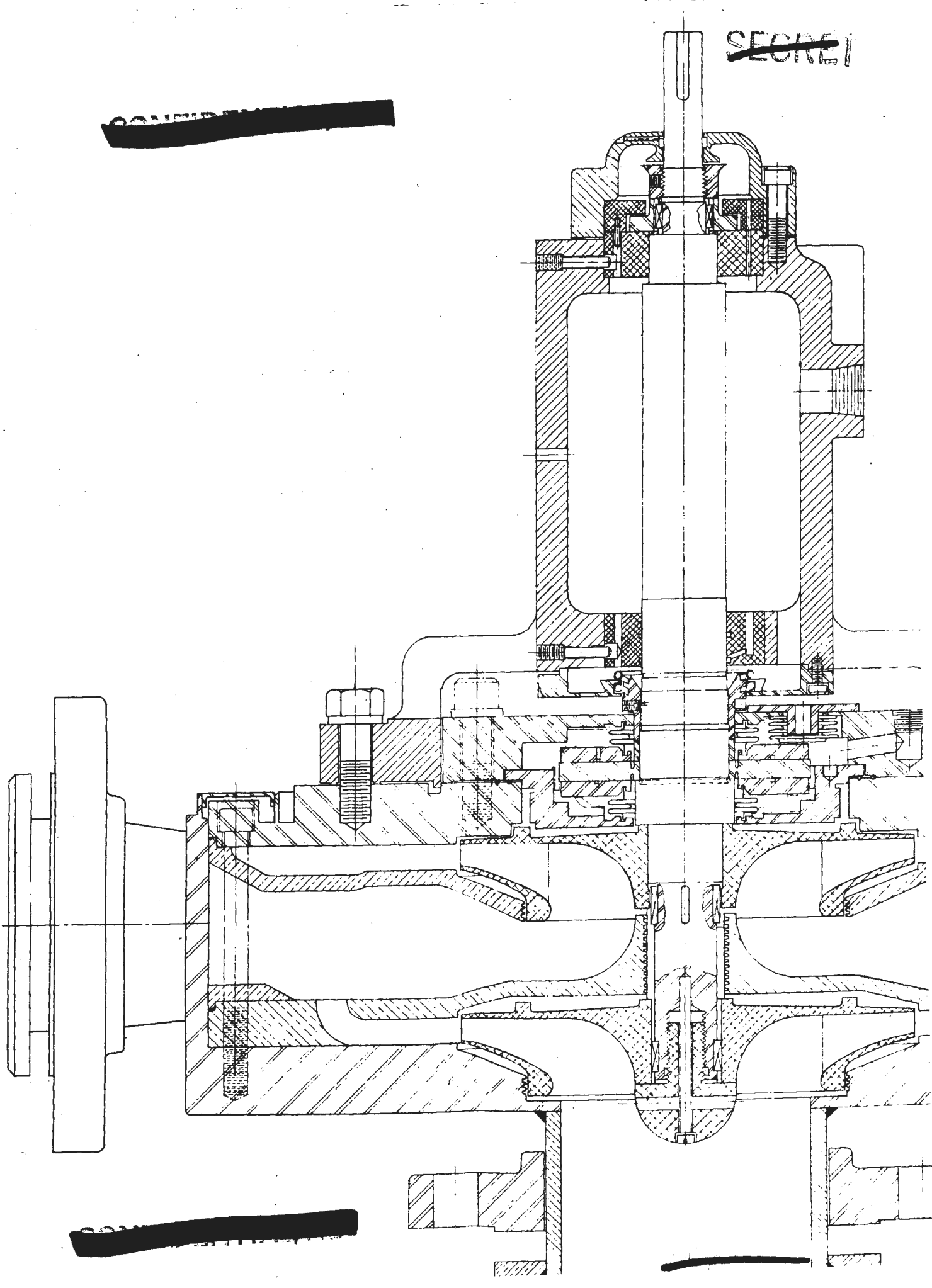
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T sheet was accordingly placed in production at the Linde plant in February 1946, and continued until the plant was placed in stand-by condition several months later.

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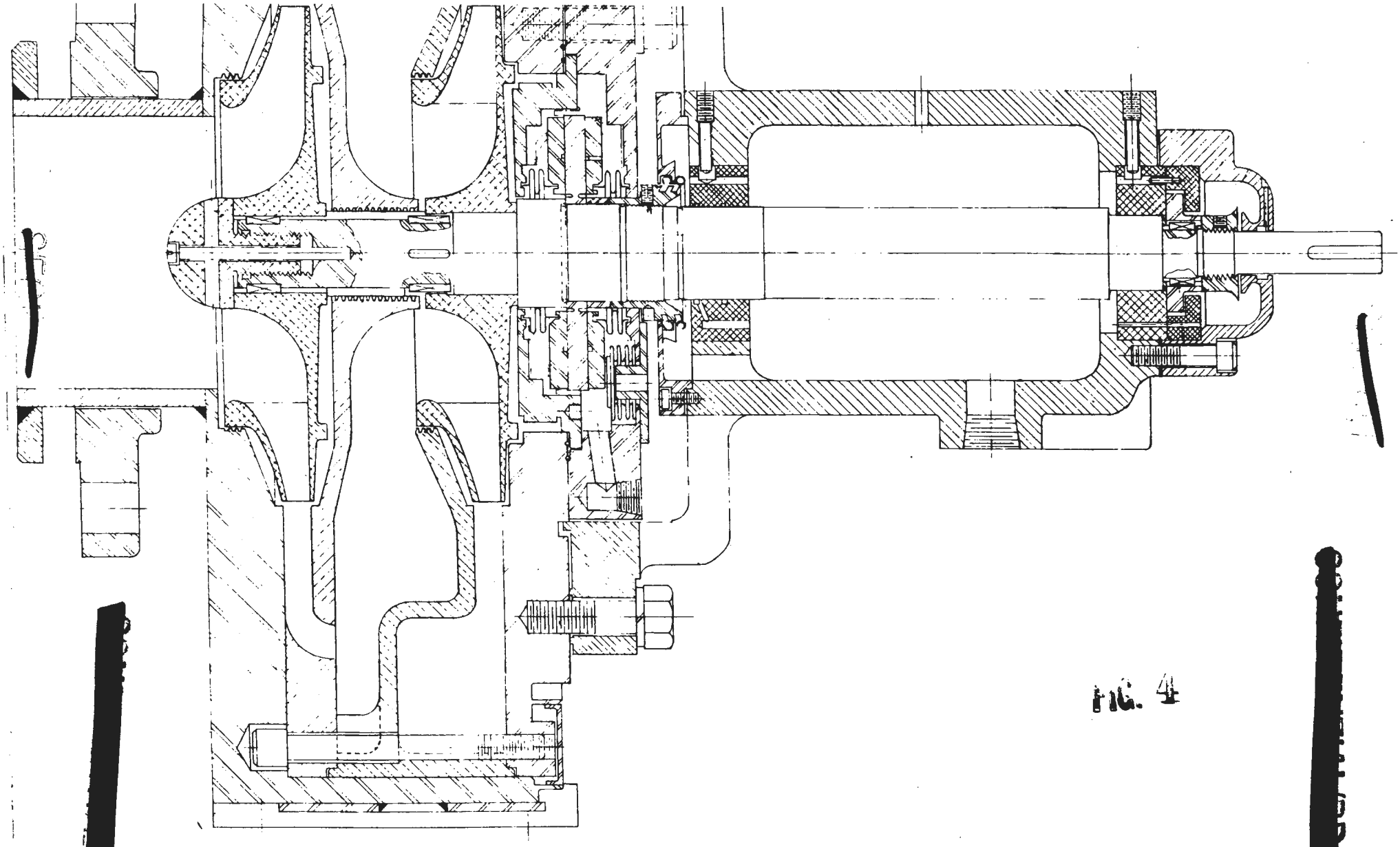
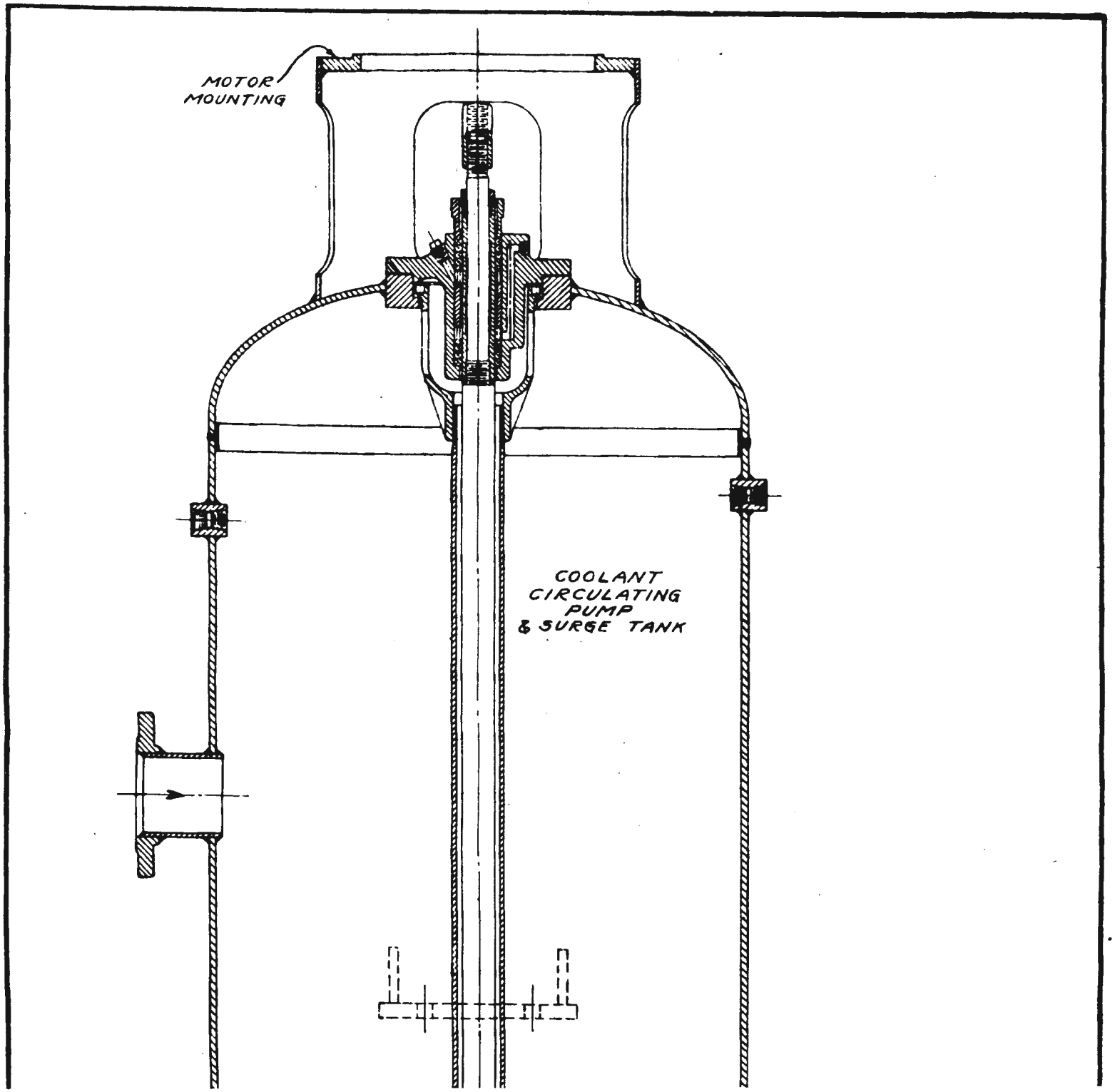


FIG. 4

ELLIOT CENTRIFUGAL CONDITIONING PUMP


MOTOR
MOUNTING
COOLANT
CIRCULATING
PUMP
& SURGE TANK

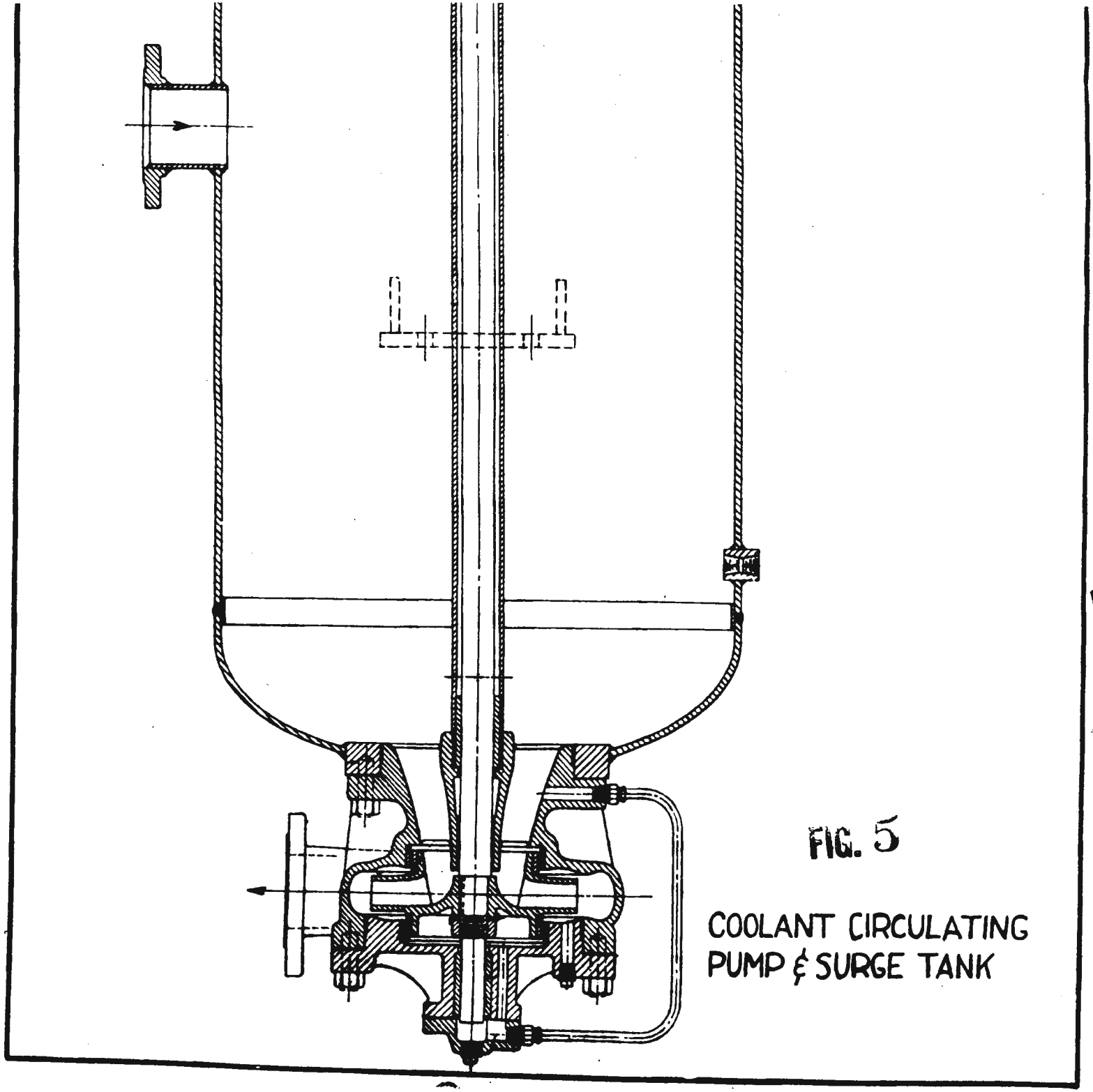


FIG. 5

COOLANT CIRCULATING
PUMP & SURGE TANK

[redacted]

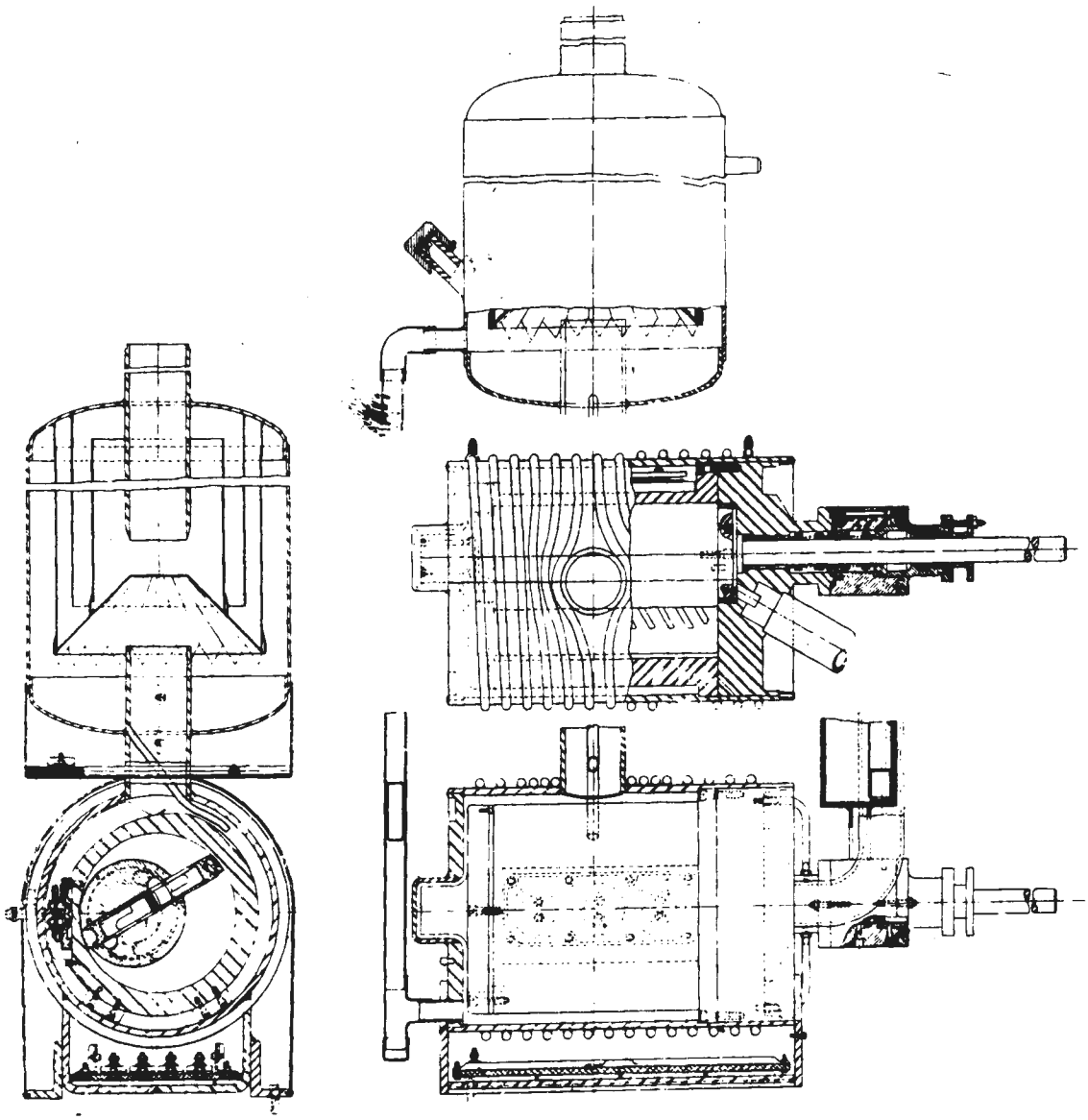
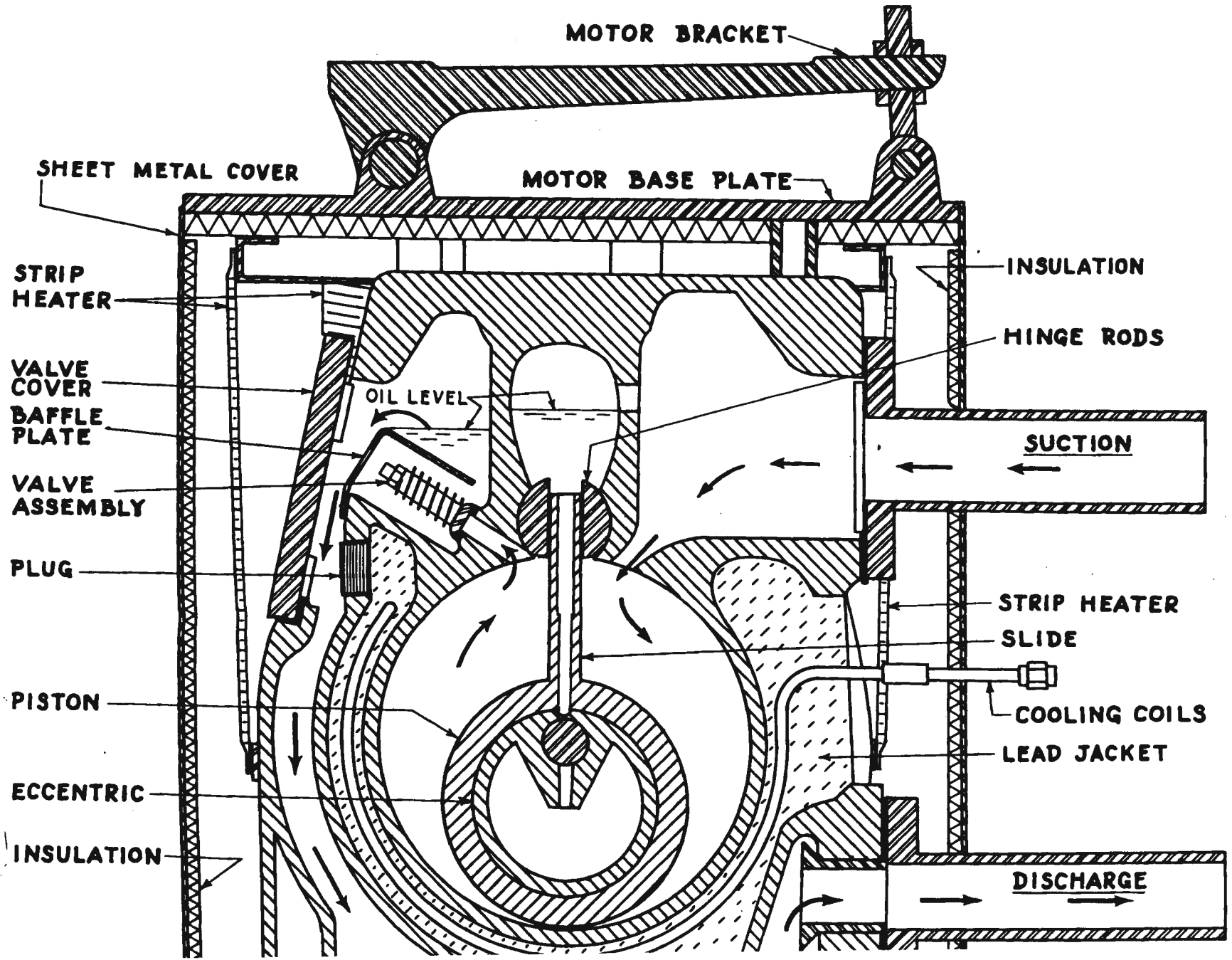
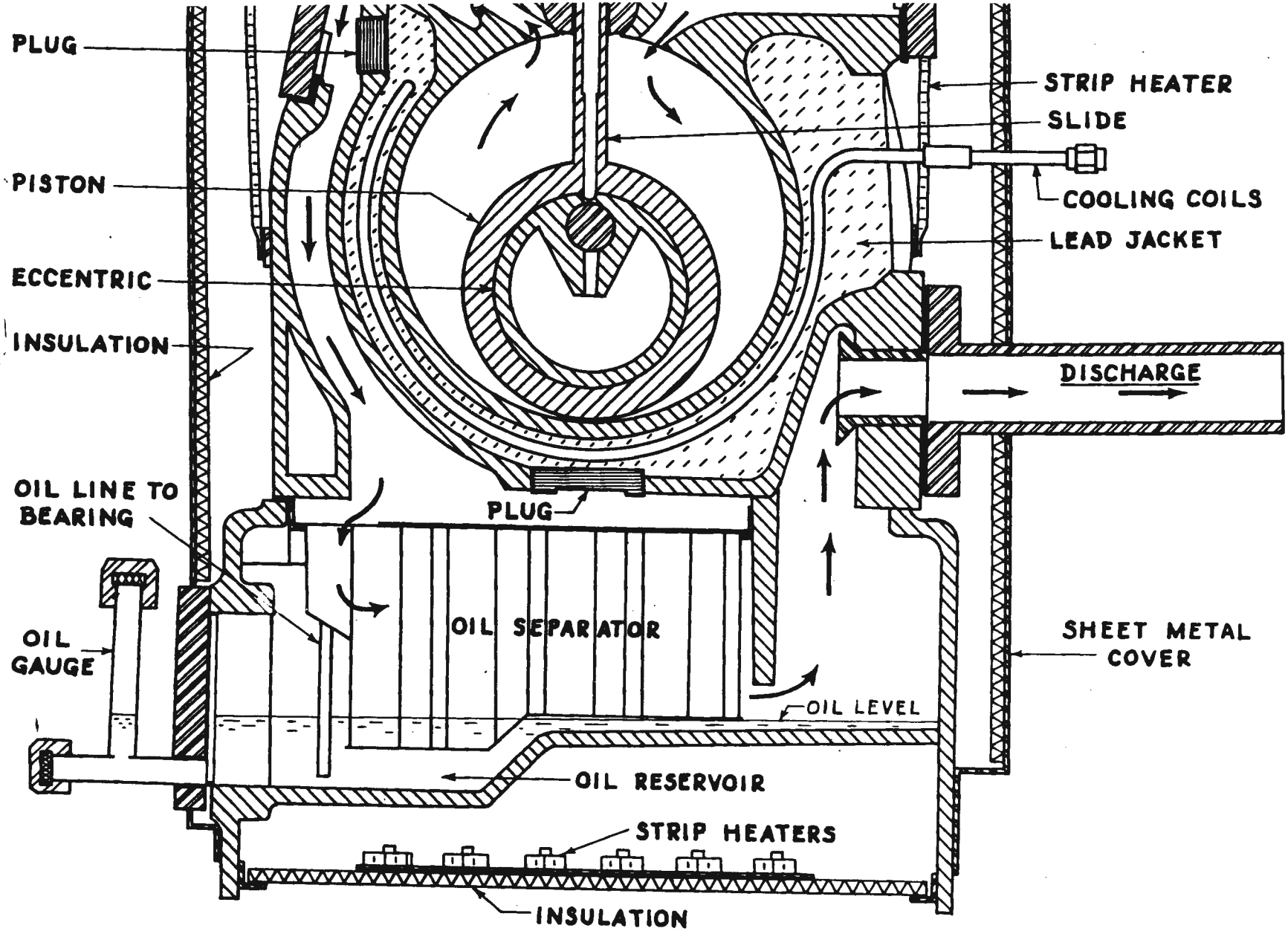


FIG. 6

[redacted]

PROCESS GAS VACUUM PUMP


MOTOR BRACKET
SHEET METAL COVER
MOTOR BASE PLATE
STRIP HEATER
INSULATION
HINGE RODS
VALVE COVER
OIL LEVEL
BAFFLE PLATE
SUCTION
VALVE ASSEMBLY
PLUG
STRIP HEATER
SLIDE
PISTON
COOLING COILS
LEAD JACKET
ECCENTRIC
INSULATION
DISCHARGE



FLORINE VACUUM PUMP

Fig. 7

STOKES
VACUUM PUMP

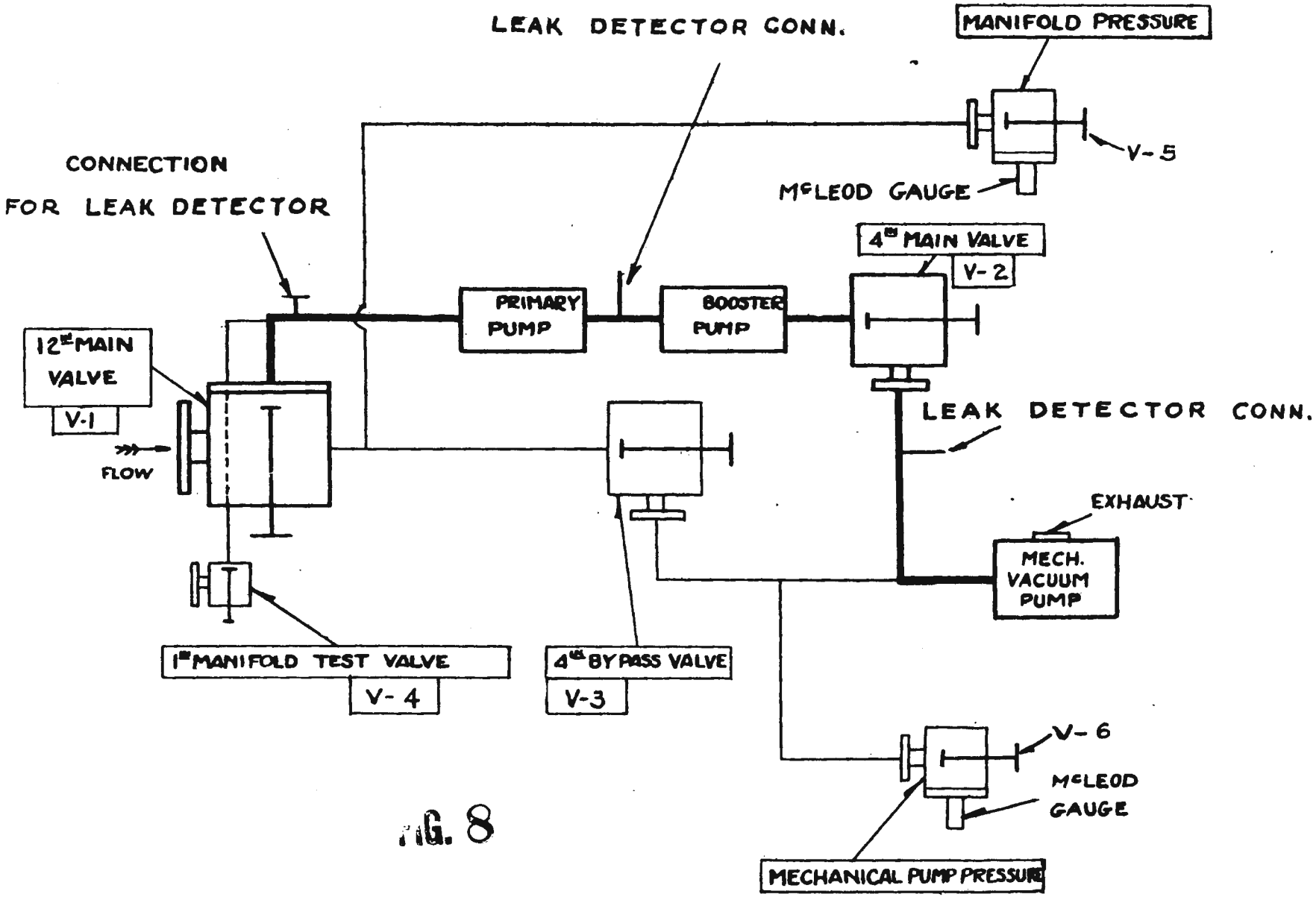


FIG. 8

VACUUM SCHEMATIC
2000 CFM PORTABLE UNIT

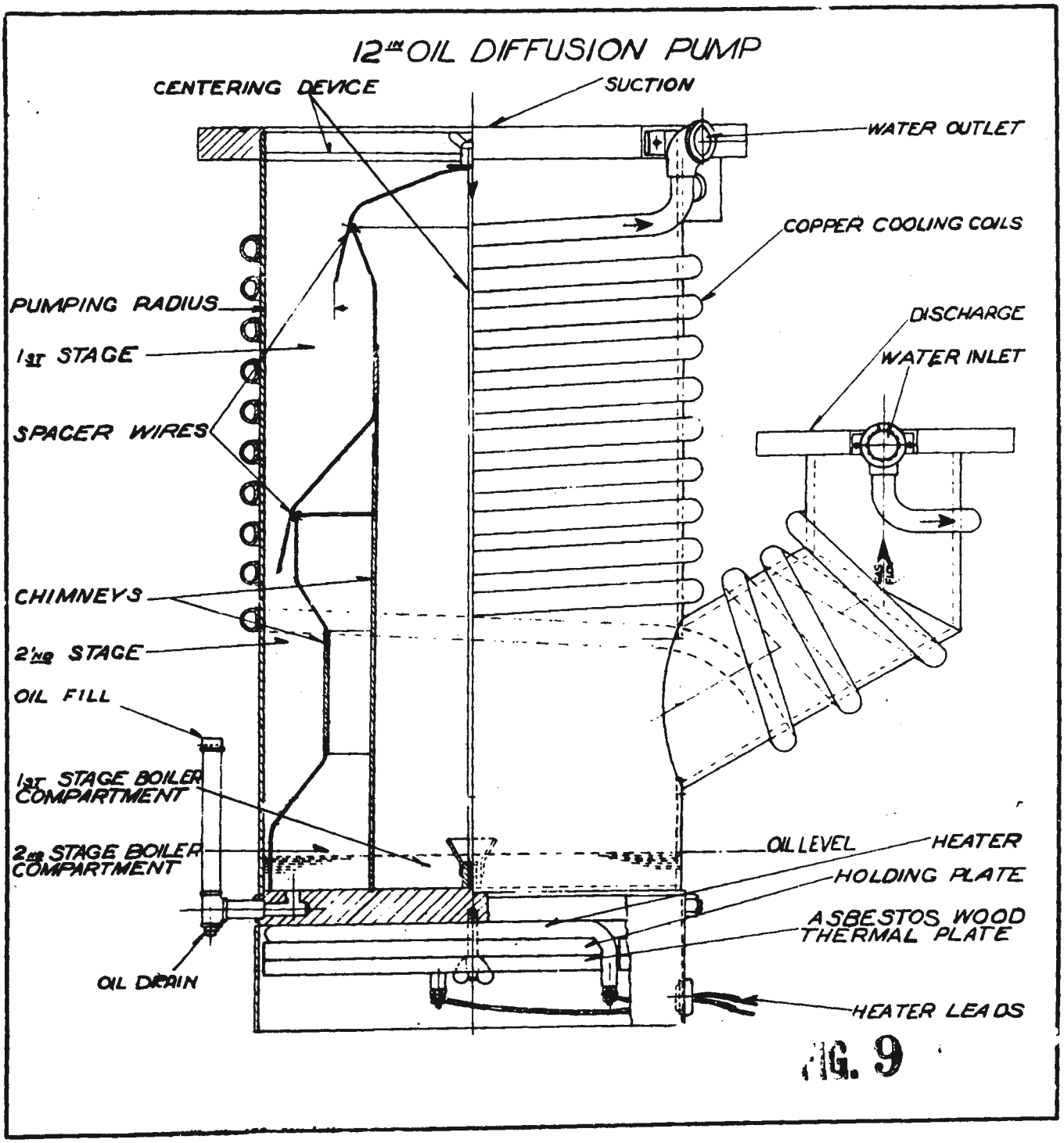
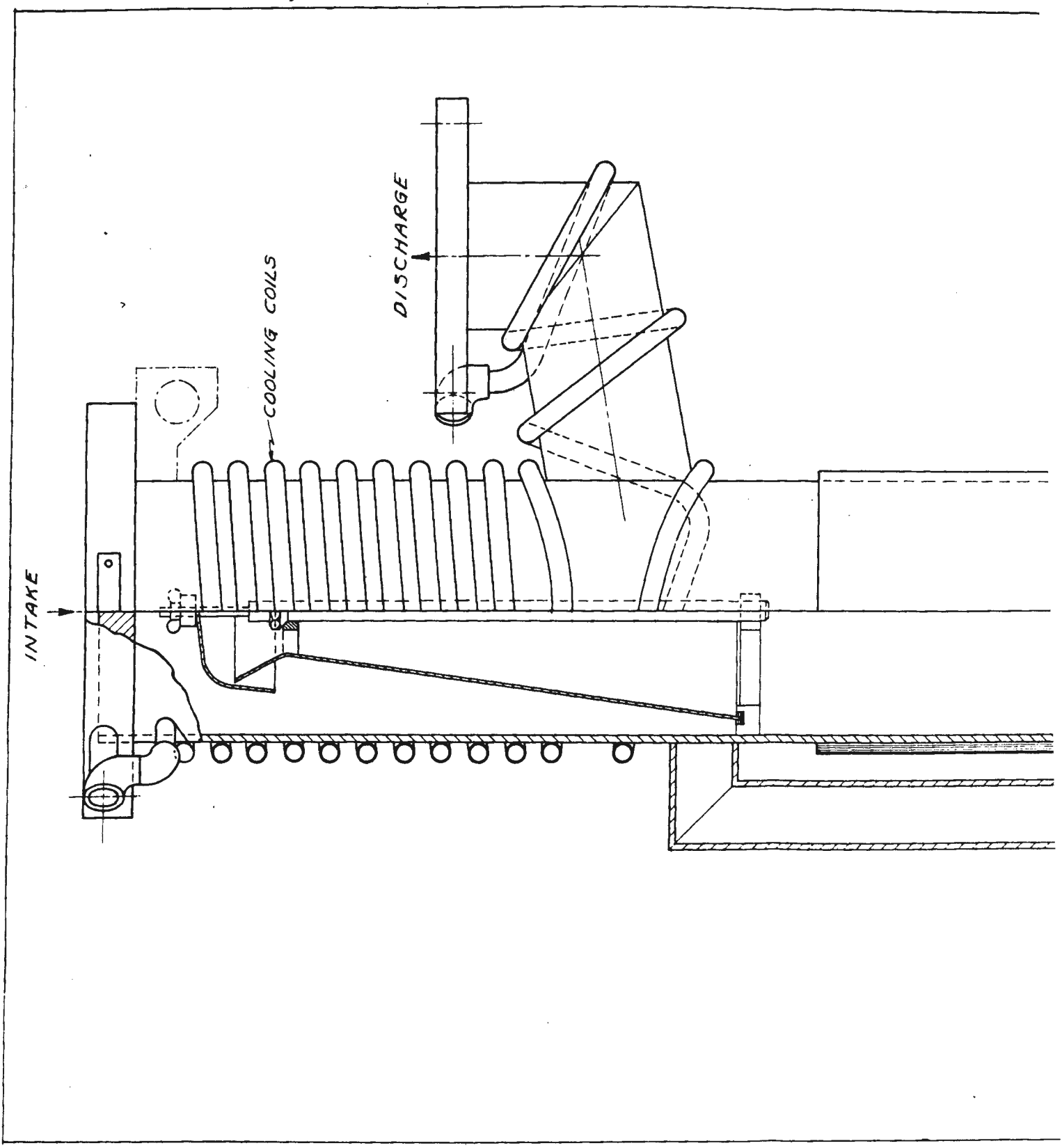

12" OIL DIFFUSION PUMP
CENTERING DEVICE
SUCTION
WATER OUTLET
COPPER COOLING COILS
PUMPING RADIUS
1ST STAGE
SPACER WIRES
DISCHARGE
WATER INLET
CHIMNEYS
2ND STAGE
OIL FILL
1ST STAGE BOILER COMPARTMENT
2ND STAGE BOILER COMPARTMENT
OIL LEVEL
HEATER
HOLDING PLATE
ASBESTOS WOOD THERMAL PLATE
OIL DRAIN
HEATER LEADS

FIG. 9

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DISCHARGE
COOLING COILS
INTAKE

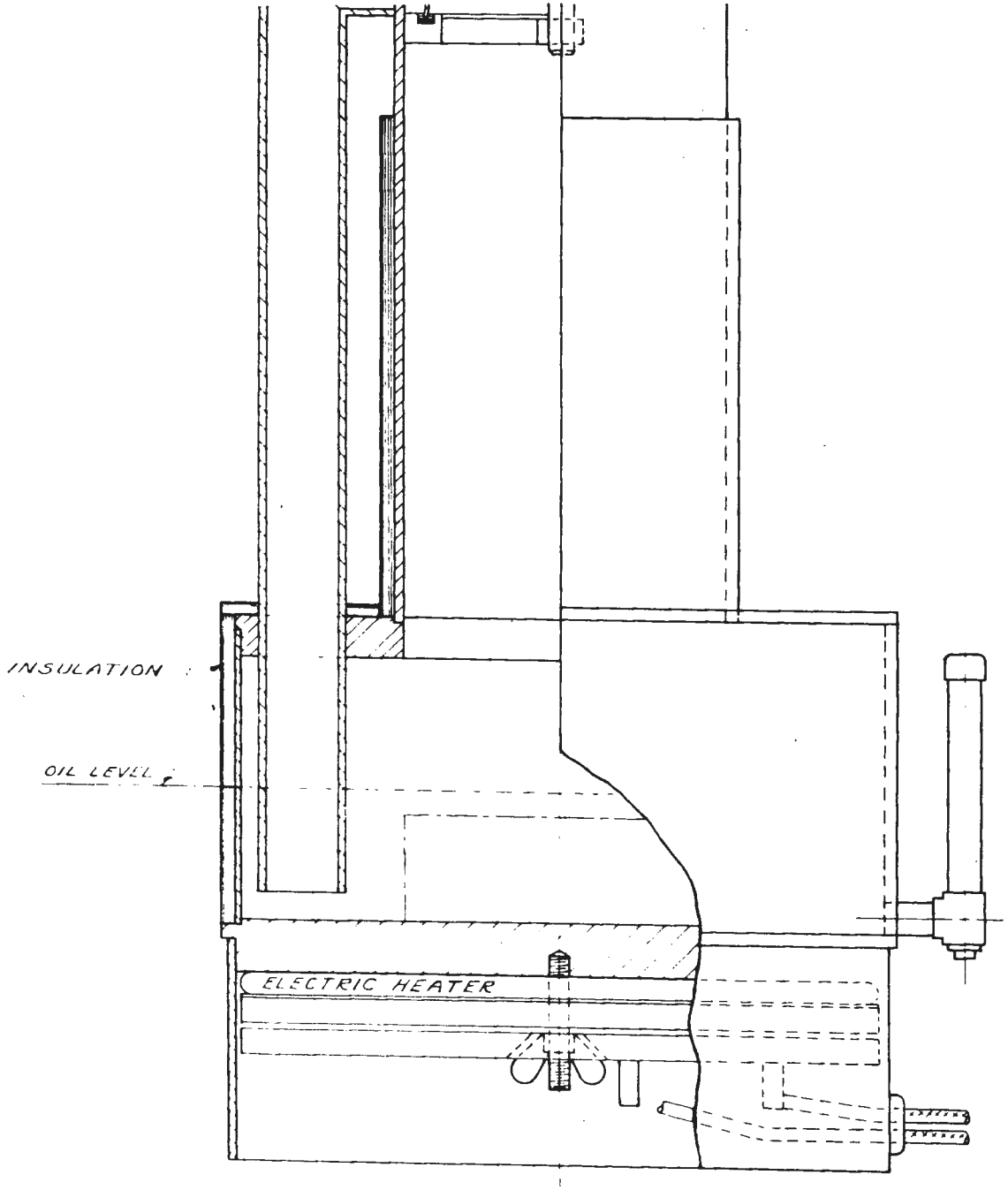


FIG. 10

BOOSTER OIL DIFFUSION PUMP

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Manhattan District History

Book II - Gaseous Diffusion [K-25] Project

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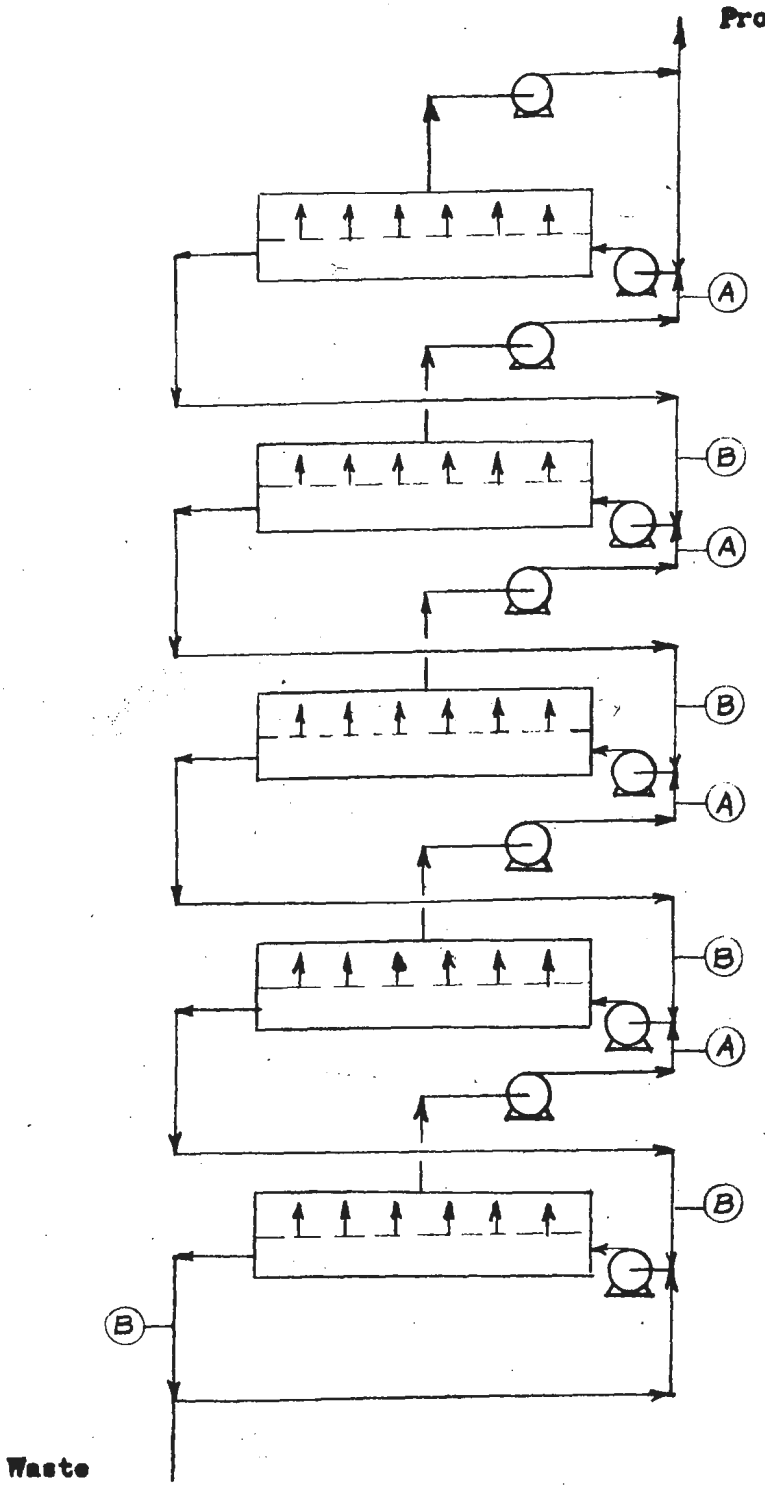
Vol. 3 - Design

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BY Michael Kelley
BY Memo DATE 5/31/13

Department of Energy Declassification Review
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Authority: ☐ DC ☒ DD
Name: K Schaffer
2nd Review Date: 4/22/13
Authority: DD
Name: R Starr
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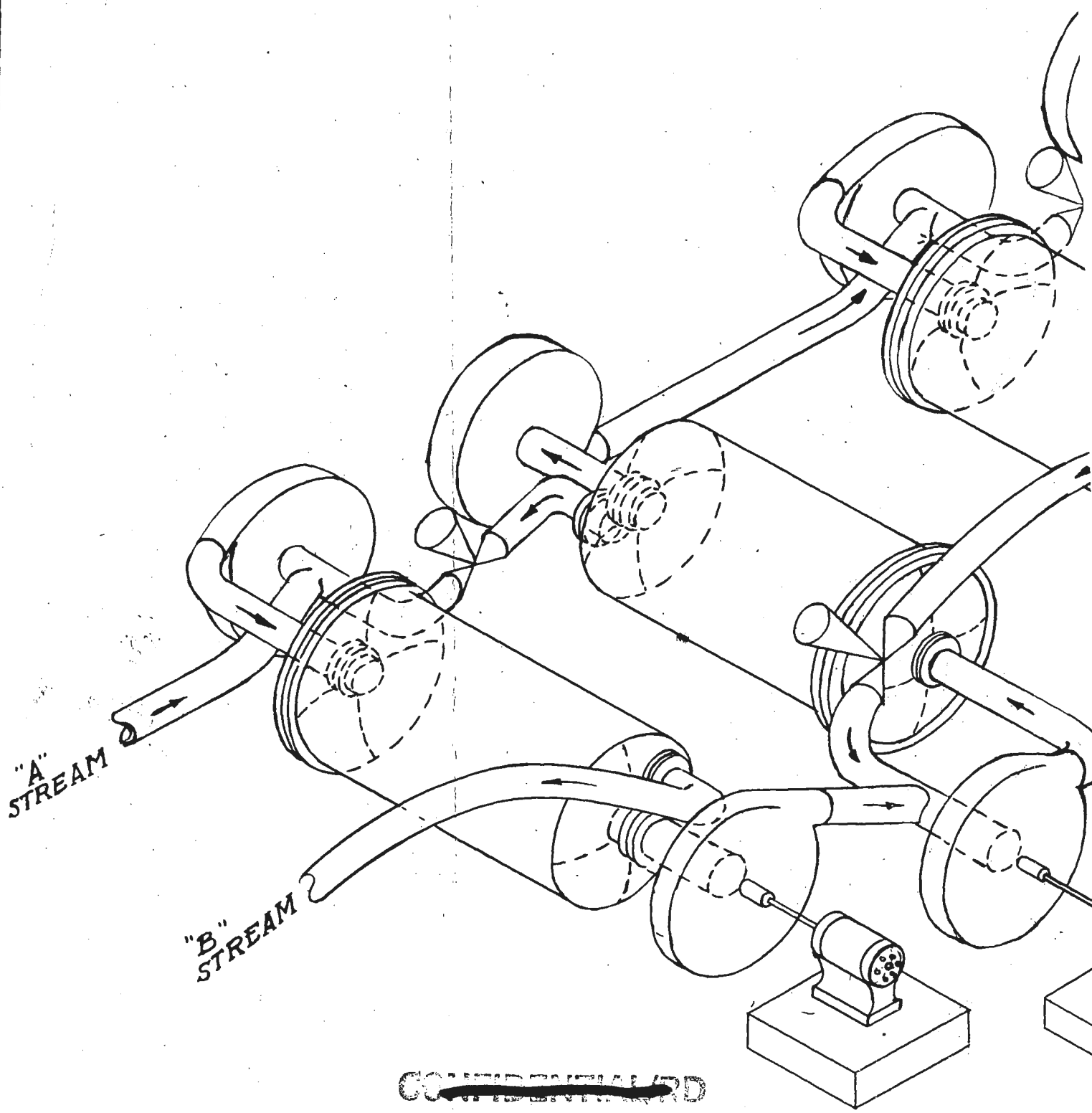
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SCHEMATIC DIAGRAM
SIMPLE DIFFUSION CASCADE

FIG. 1


"A"
STREAM
"B"
STREAM

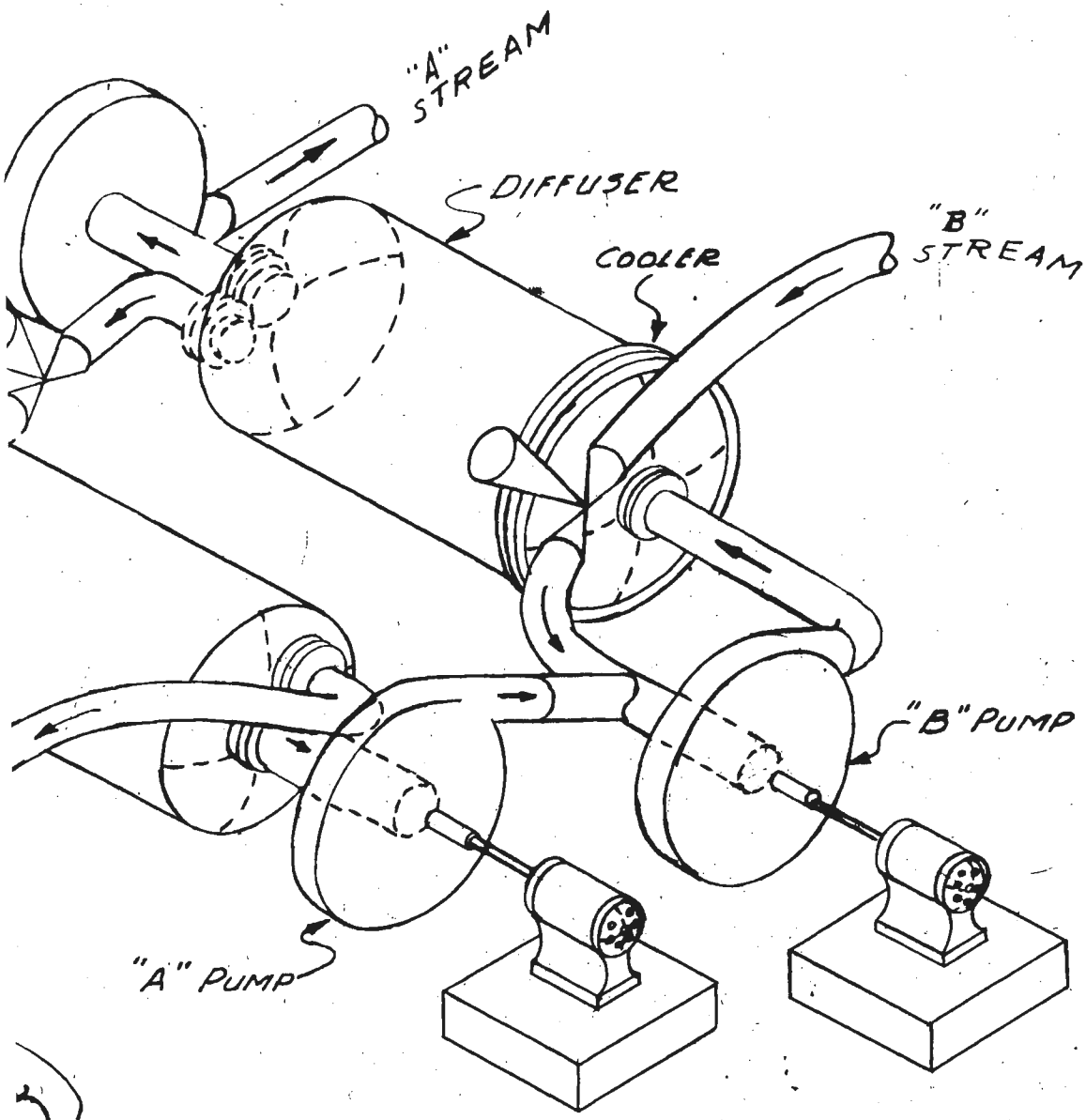
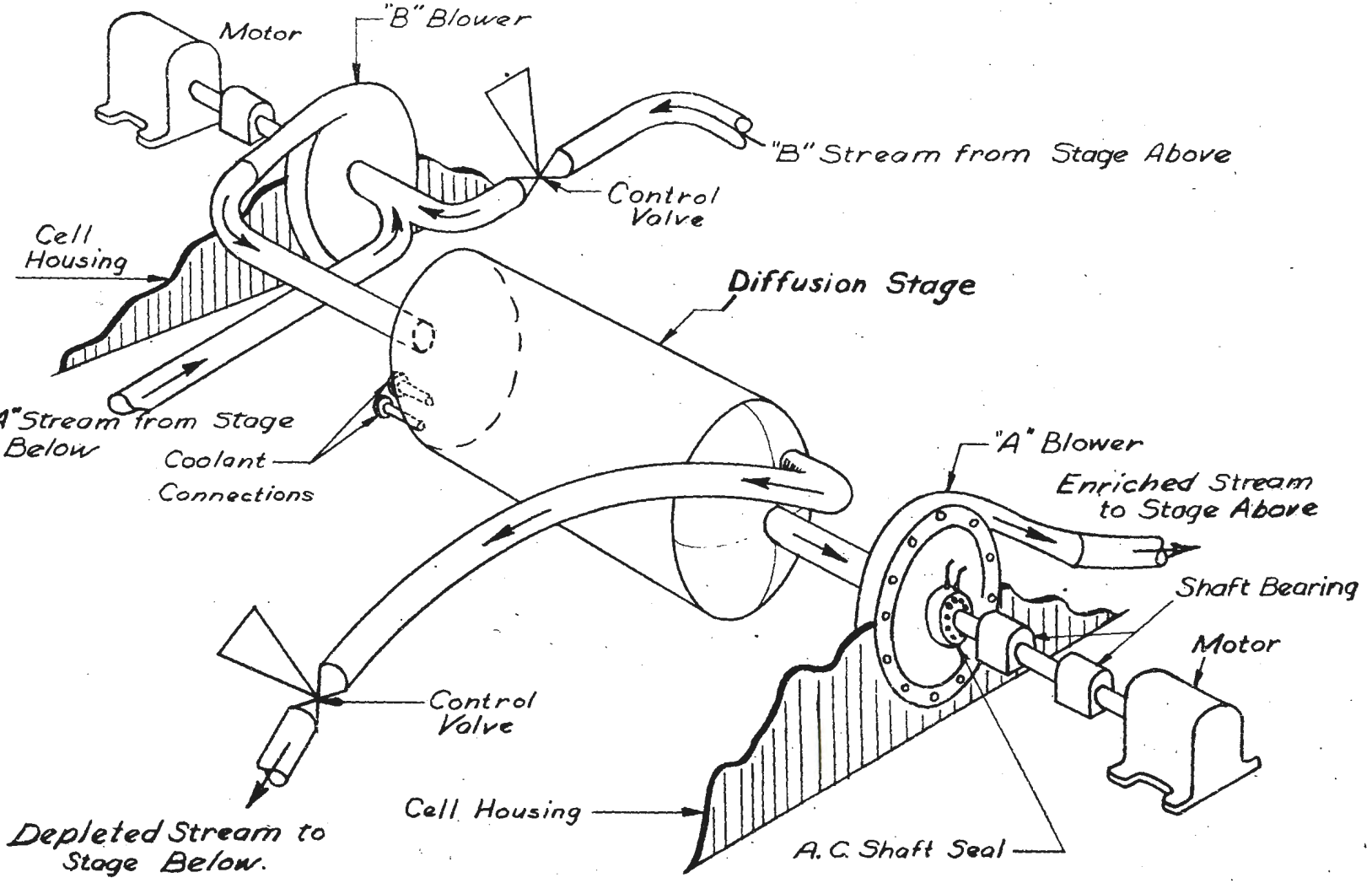


FIG. 3

CASCADE OF FOUR STAGES

FIG. 4



TYPICAL STAGE

WMW
8-17-46

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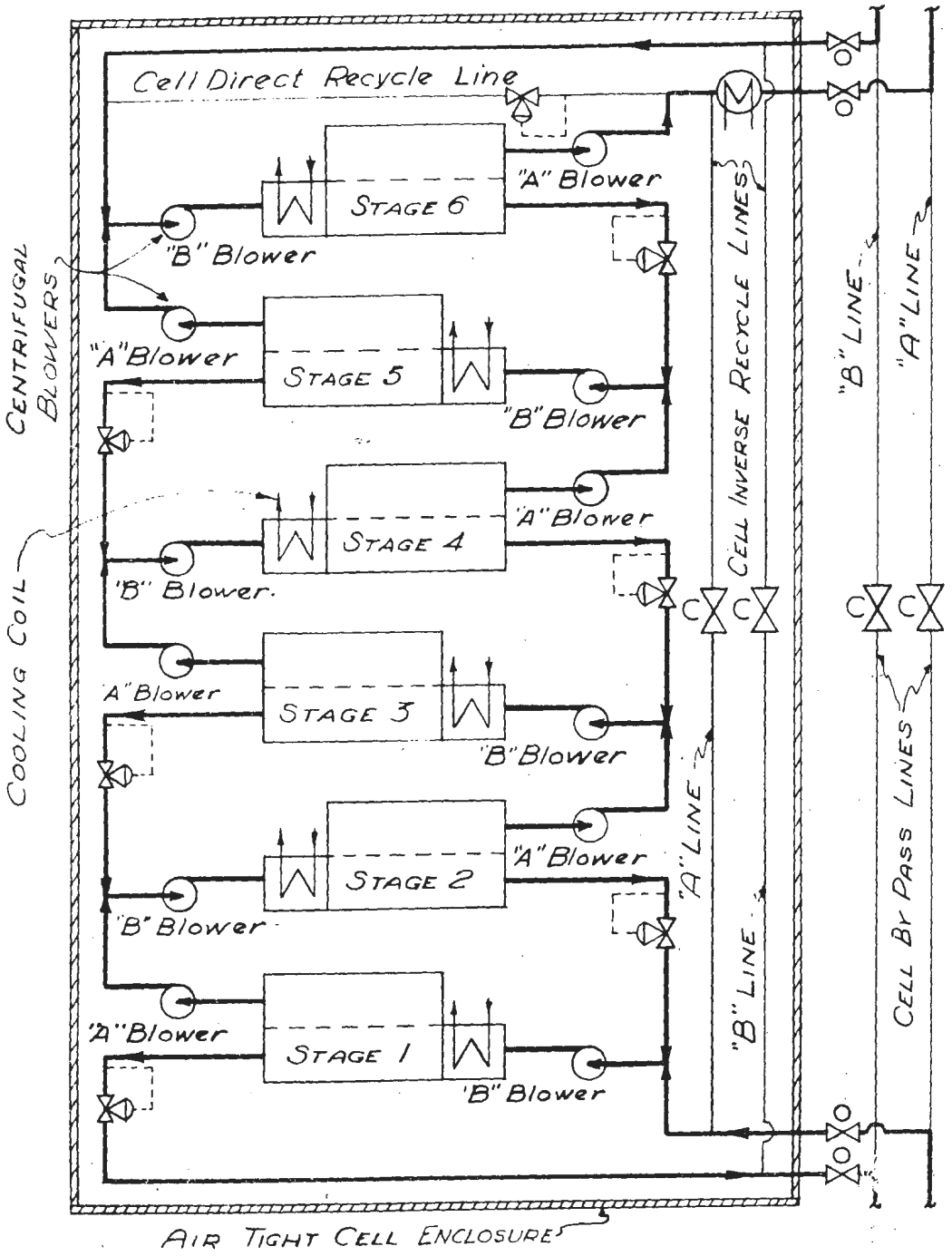


Diagram of a Typical Cell
(Heavy lines indicate normal gas flow.)

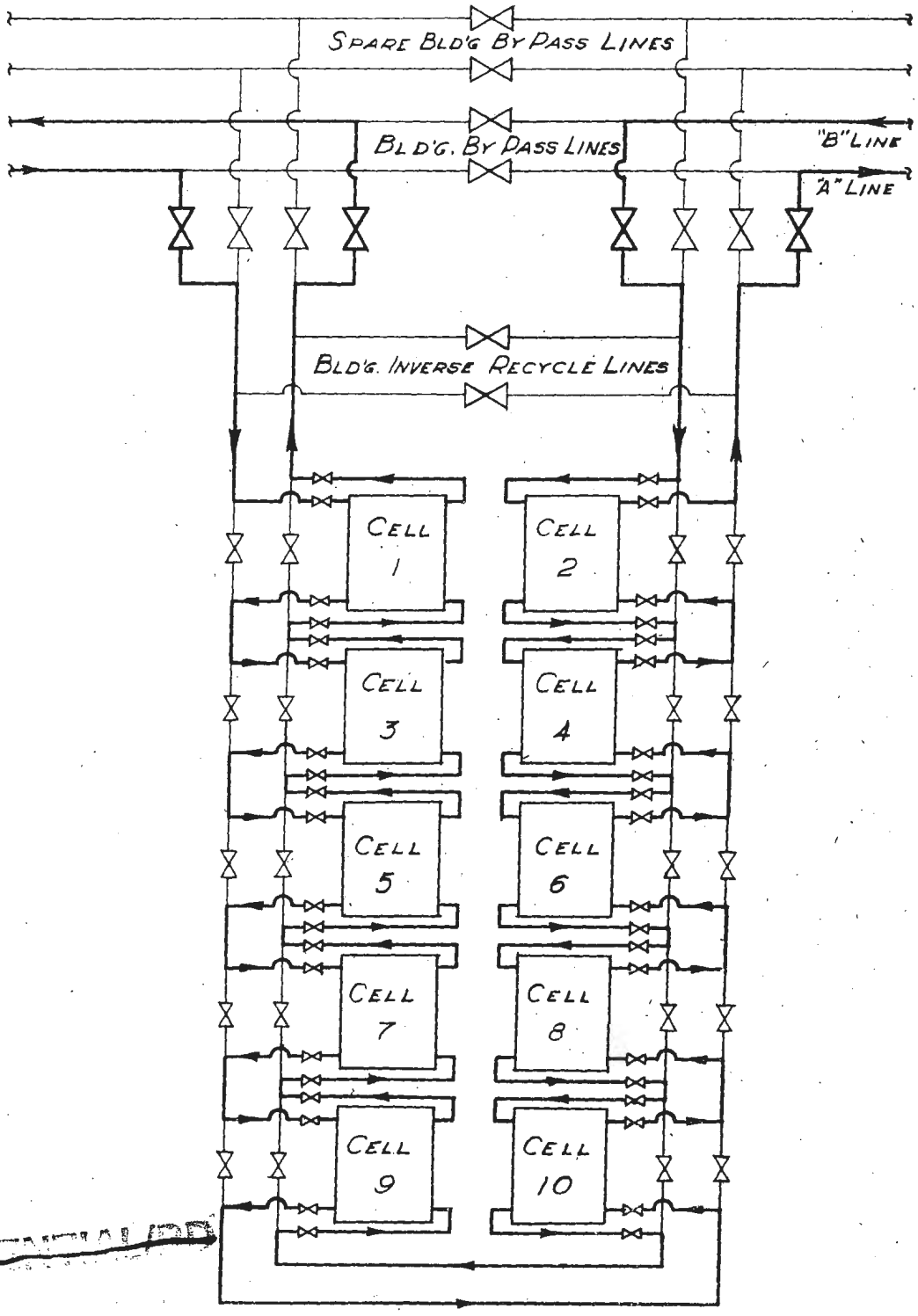
FIG. 5

Valves normally open
Valves normally closed
Automatic pressure regulating valve.

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Fig. 6

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Diagram of Piping & Valves in a Typical Building

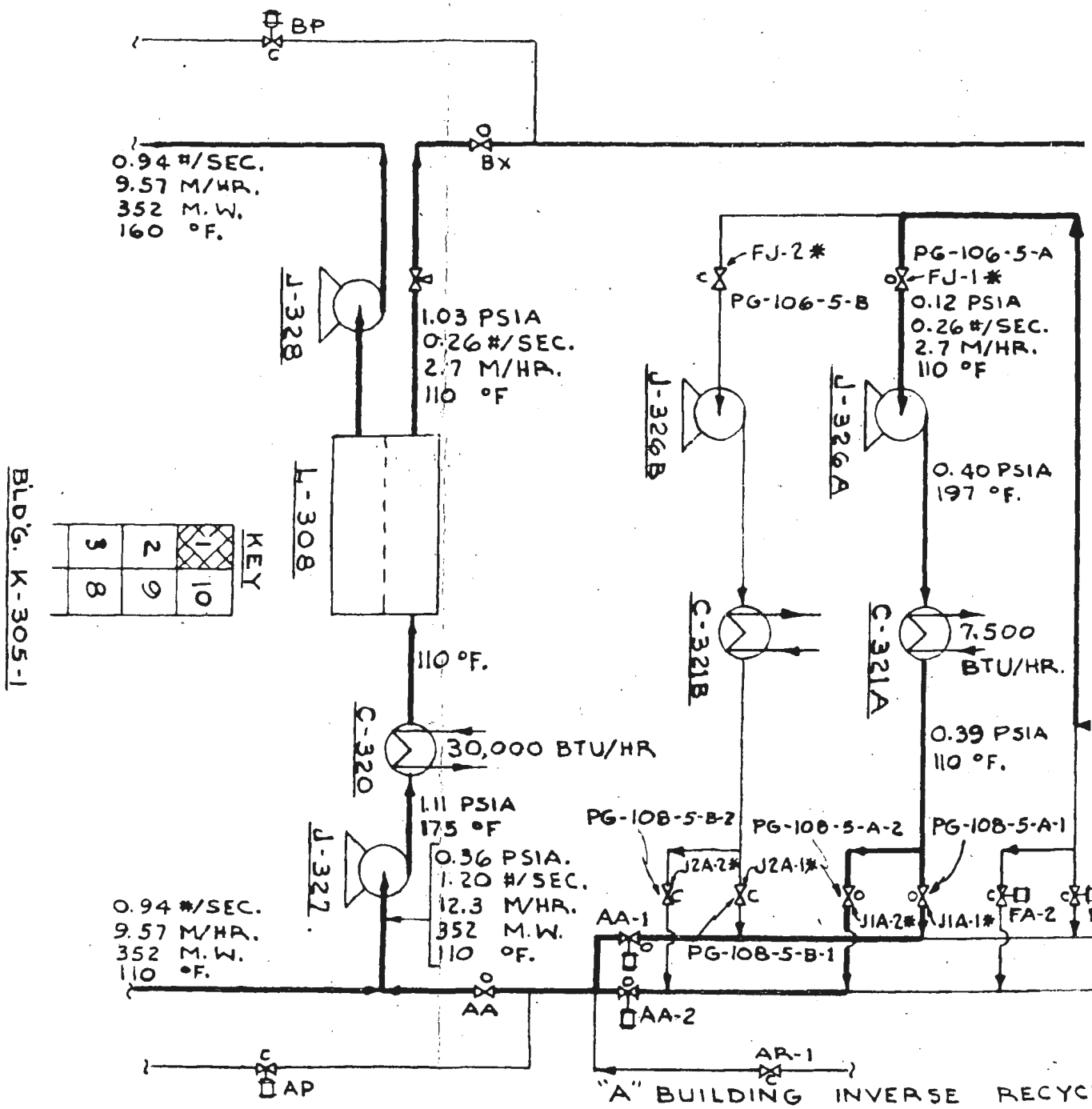
(Heavy lines indicate normal gas flow).

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TABLE 2. - CASCADE SECTION DATA

CASCADE SECTION NUMBER	BUILDING DESIGNATION	NUMBER OF BUILDINGS	NUMBER OF CELLS	NUMBER OF STAGES	SIZE OF EQUIPMENT	TYPICAL CONVERTER PRESSURE (p.s.i.a.)	INTERNAL CONVERTER TEMPERATURE °F	RATED PUMP CAPACITY "A" (c.f.m.)	RATED PUMP CAPACITY "B" (c.f.m.)
-3	K-311	1	9	54	3	2.0	140	3800	3800
-2	K-310	3	21	126	2	2.3	140	9200	9200
-1	K-306	3	15	90	1	2.3	140	9600	11200
1	K-301	6	37	222	1	2.3	140	9600	11200
2a	K-302	5	46	276	2	2.2	140	9200	9200
2b	K-303	10	92	552	2	1.6	140	9200	9200
3a	K-304	6	48	288	3	1.3	110	3800	3800
3b	K-305	12	118	708	3	0.7	110	3800	3800
4	K-306	7	96	576	4	0.5	110	1200	1200
		51	482	2892					

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PROCESS FLOW DIAGRAM-

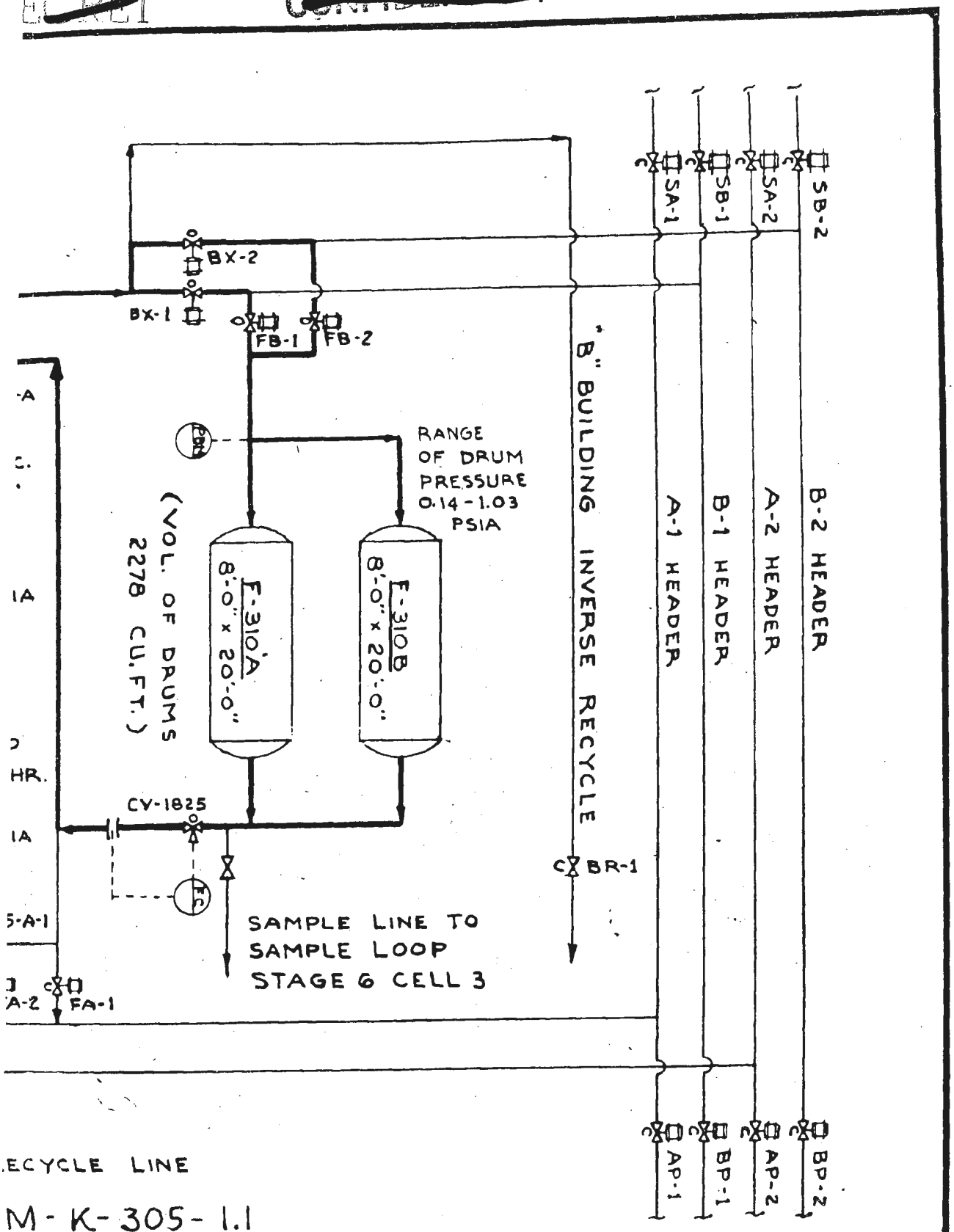
* VALVE DESIGNATION IN MASTER CONTROL ROOM.

MOTOR OPERATED VALVES

(BOTTO

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.ECYCLE LINE

M-K-305-1.1

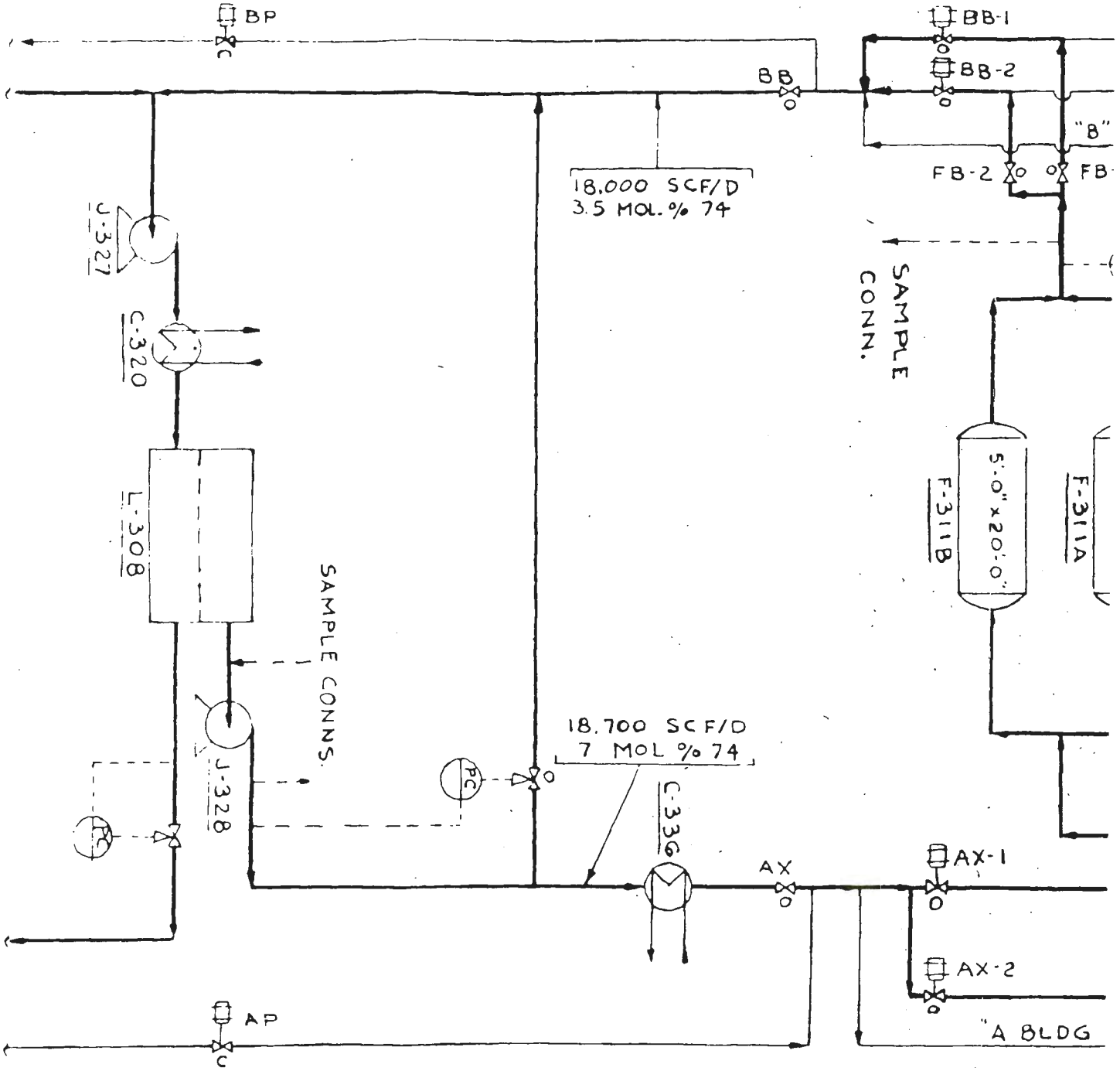
'TOM INT. CELL)

FIG. 7

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PROCESS FLOW DIAGRAM - K-3

BLDG. K-305-12

KEY

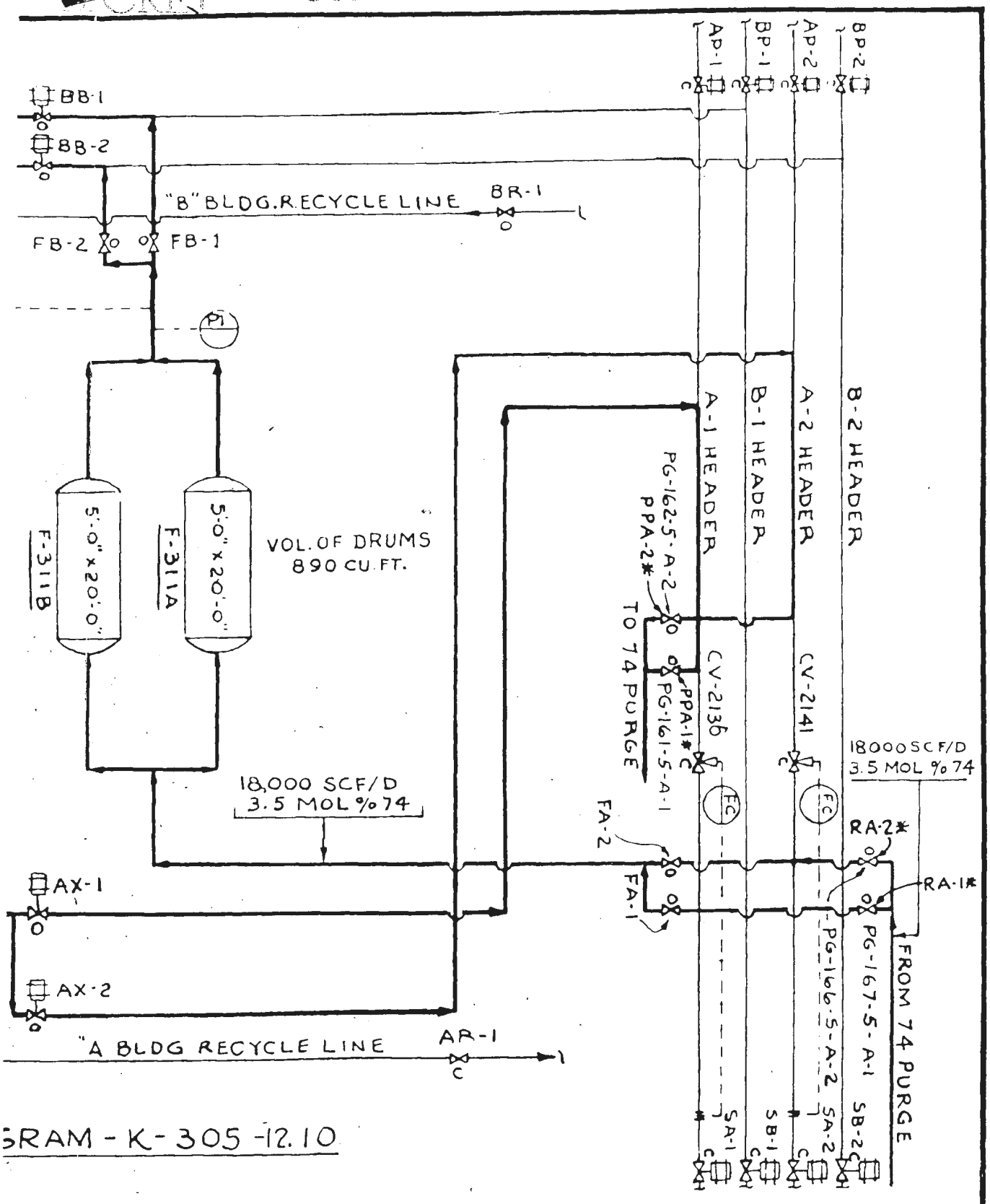
5	4	3	2	1
6	7	8	9	10

MOTOR OPERATED VALVE.

* VALVE DESIGNATION IN MASTER CONTROL ROOM.

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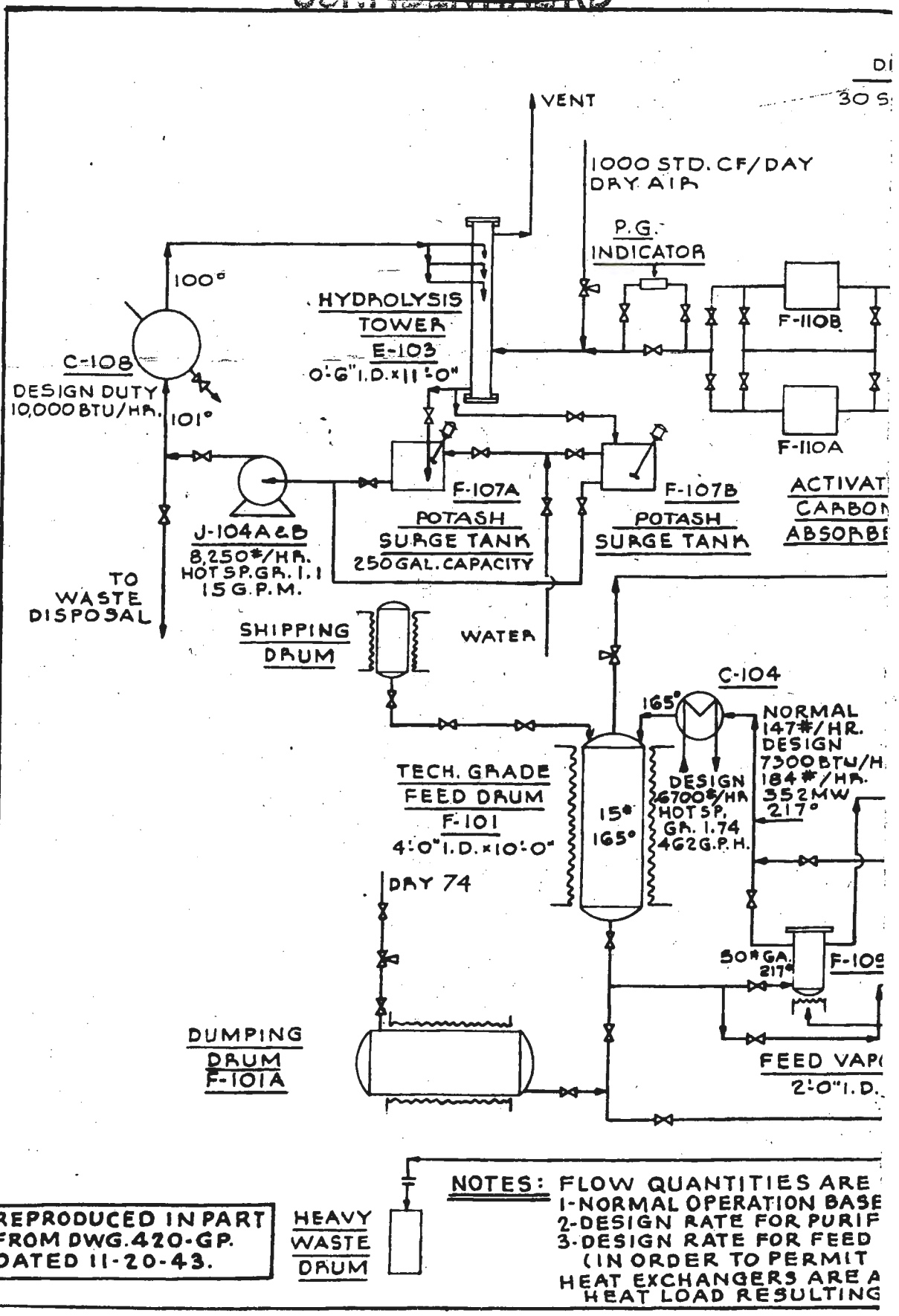


SRAM-K-305-12.10

(TOP INT. CELL)

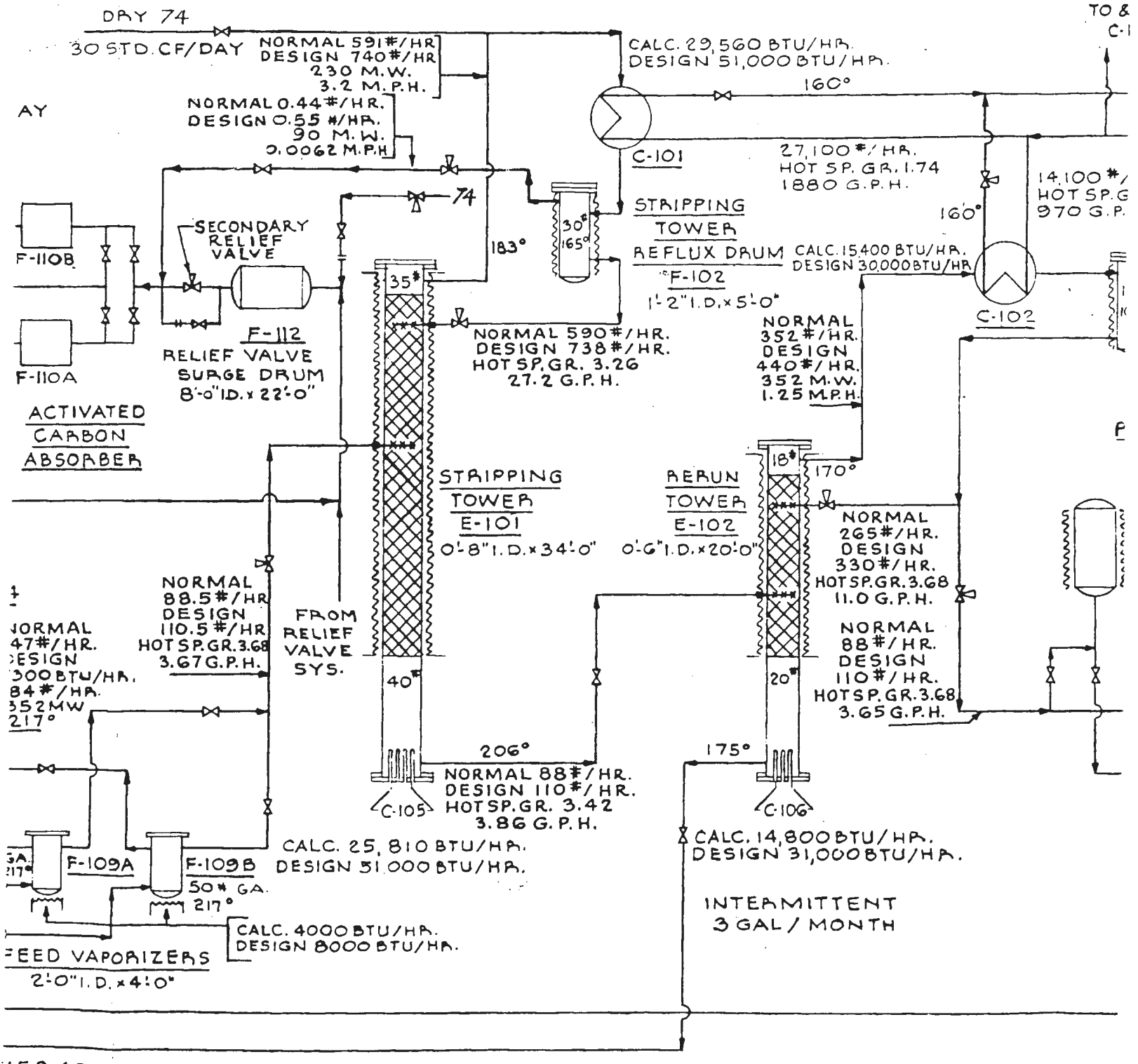
FIG. 8

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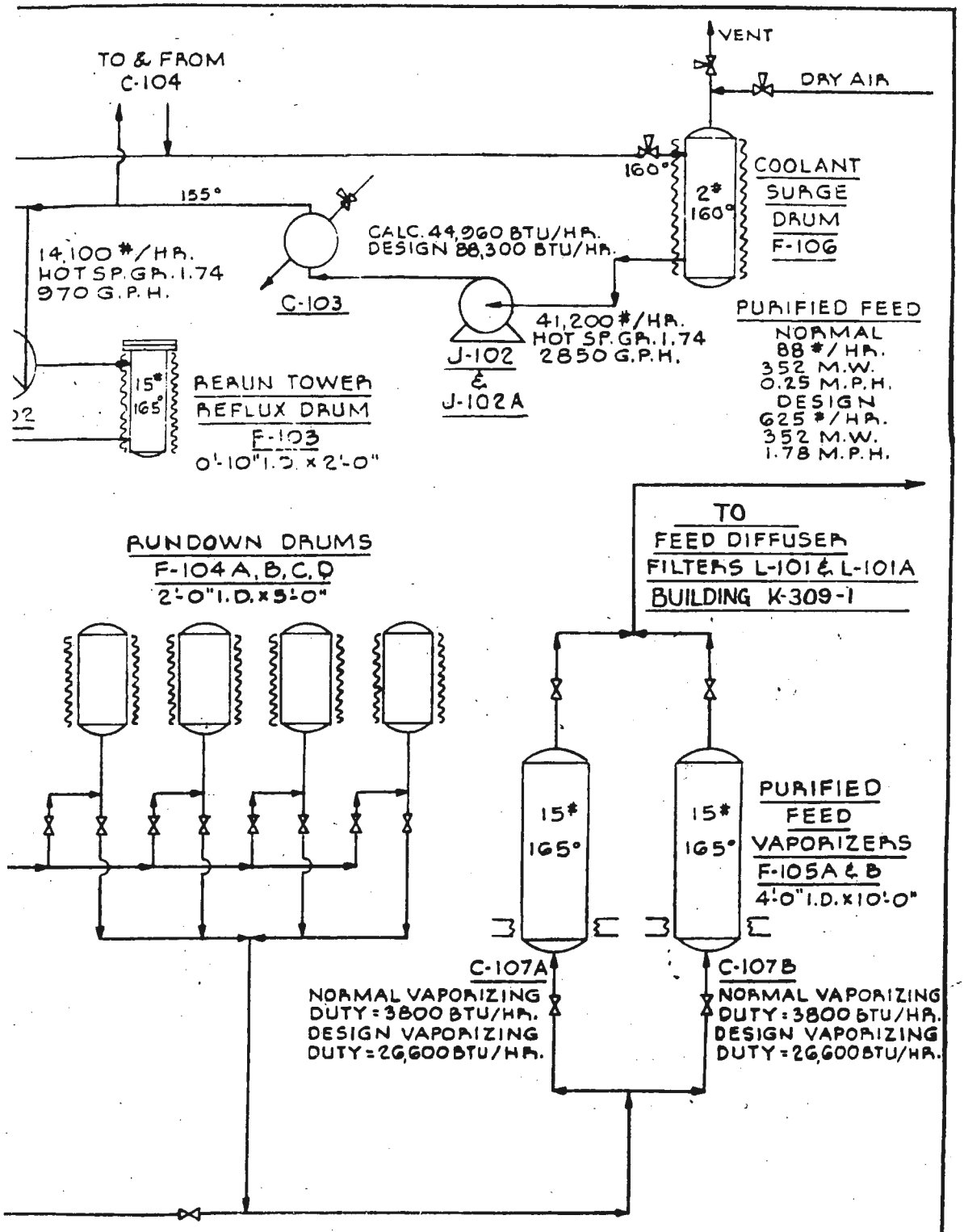


IES ARE SHOWN FOR:
TION BASED ON FEED RATE TO THE MAIN PLANT OF 2,108#/DAY.
OR PURIFICATION EQUIPMENT 25% ABOVE NORMAL.
OR FEED VAPORIZERS BASED ON FEED RATE OF 15,000#/DAY
PERMIT FILLING ENTIRE CASCADE IN 48 HRS.
RS ARE ALL DESIGNED FOR APPROXIMATELY TWICE THE
ESULTING FROM DESIGN RATES OF FLOW.

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[redacted]

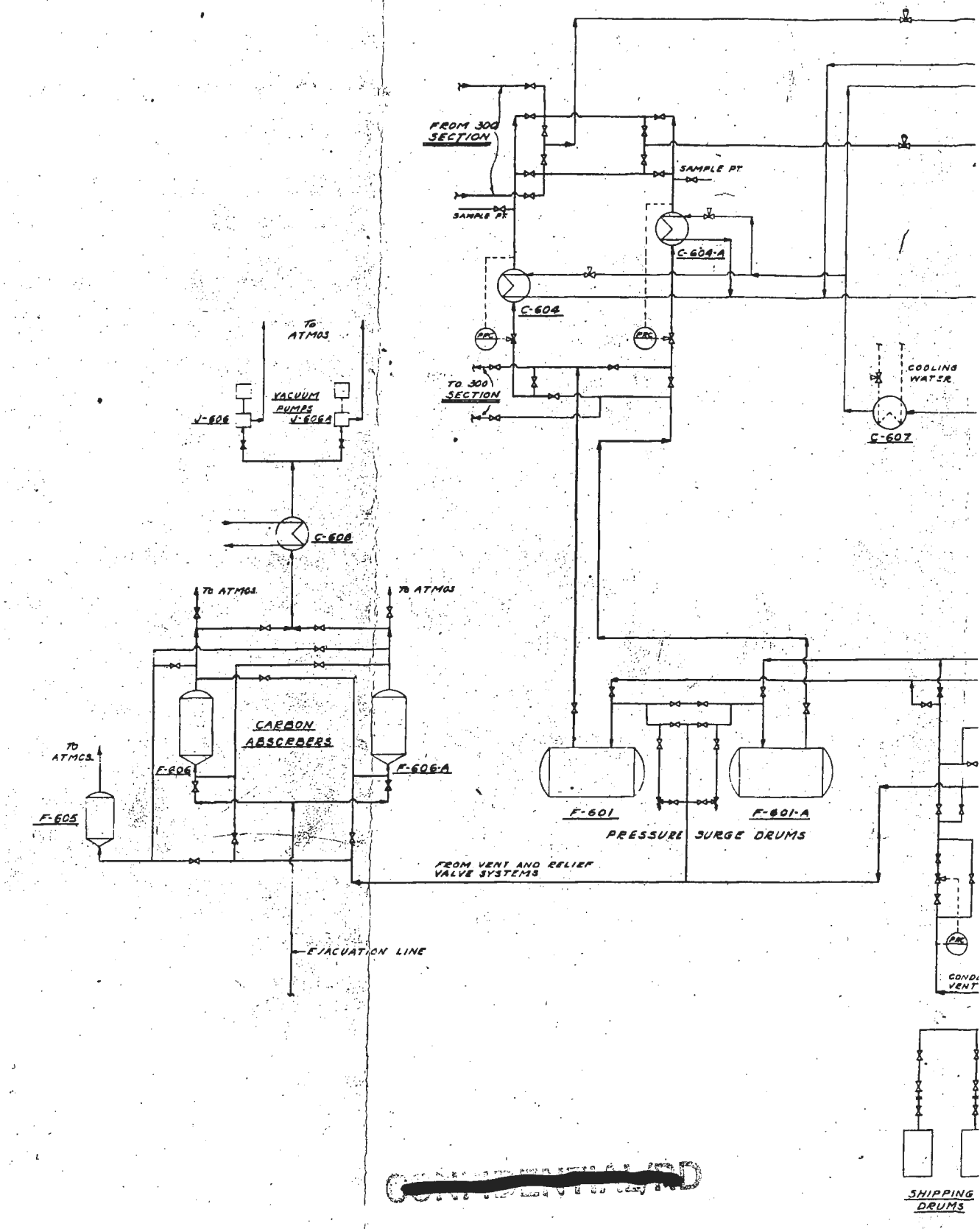


TITLE - PROCESS FLOW SHEET
FEED PREPARATION UNIT

FIG. 9

THE KELLEX CORP.	SCALE NONE DATE 11-20-43 AP ____ DR NLD TR FD CKD. ____ No. 202 O.D.

[redacted]


FROM 300 SECTION
SAMPLE PT
SAMPLE PT
C-604-A
C-604
PRC
PRC
TO 300 SECTION
COOLING WATER
C-607
TO ATMOS
VACUUM PUMPS
V-606
V-606A
C-608
TO ATMOS.
TO ATMOS
CARBON ABSORBERS
TO ATMOS.
F-606
F-606-A
F-605
F-601
F-601-A
PRESSURE SURGE DRUMS
FROM VENT AND RELIEF VALVE SYSTEMS
EVACUATION LINE
PRC
SHIPPING DRUMS

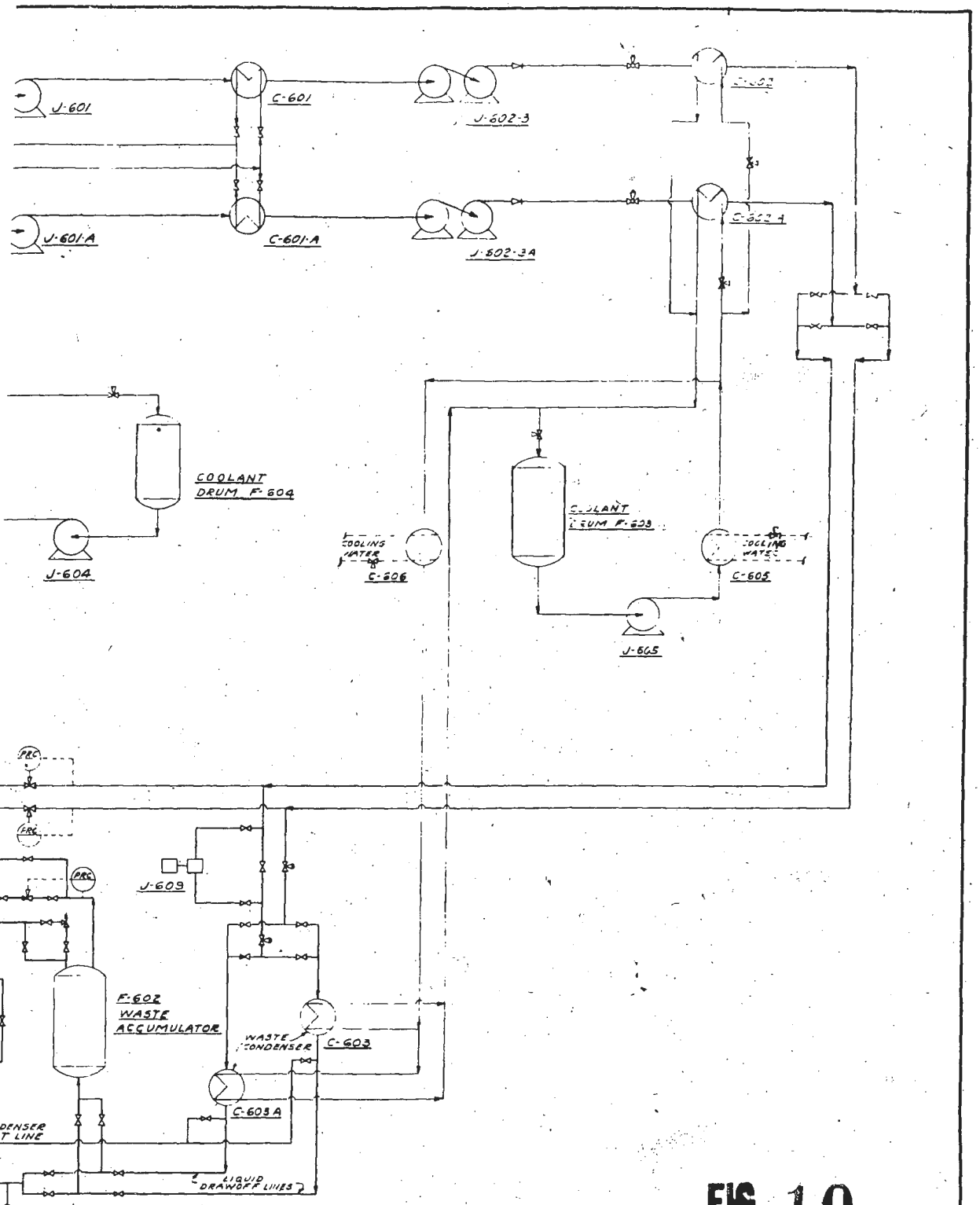


FIG. 10

NO	DESCRIPTION	DATE	BY	CHECKED
REVISIONS				

THE KELLEX CORPORATION

PROCESS FLOW SHEET FOR SURGE AND WASTE SYSTEM

FOR

DRAWN F.C.T. TRACED SCALE DATE 11/1/45

CHECKED

APPROVED

No. 332 - AP

NOTES:

A - HEAVY LINE SHOWS FLOW WHILE COLD TRAP A IS CONDENSING AND COLD TRAP B IS BEING HEATED.

B - COLD TRAP RELIEF SYSTEMS IN SECTIONS -3 THRU 2b ONLY; BY-PASSES CARBON TRAP IN SECTION 2b ONLY

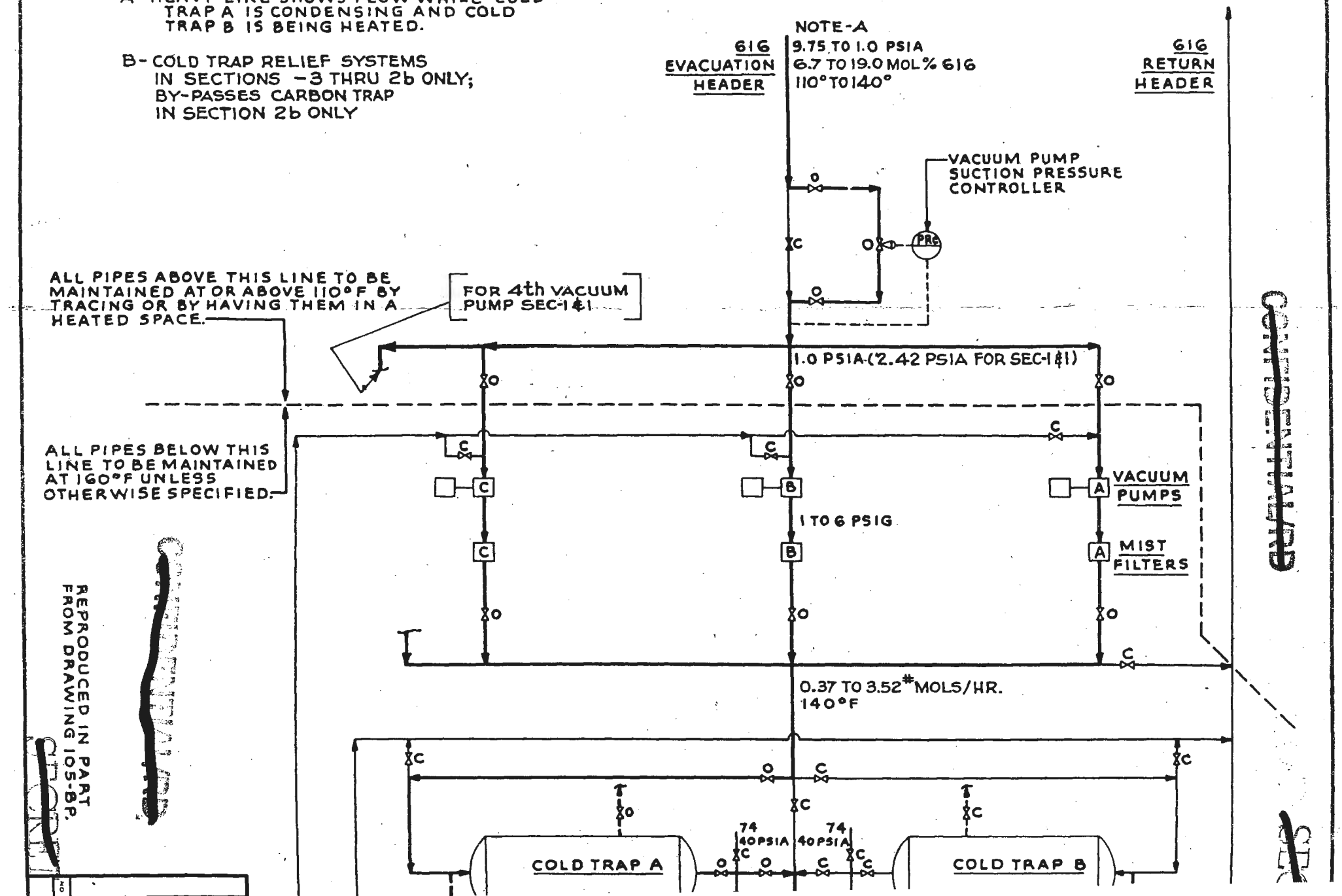


Fig. 1

THE KELLEX CORPORATION

SCHEMATIC FLOW DIAGRAM

PROCESS GAS FLOW G16 RECOVERY SYSTEMS

FOR

DRAWN ____ TRACED ____ SCALE ____ DATE ____

CHECKED ____

APPROVED ____

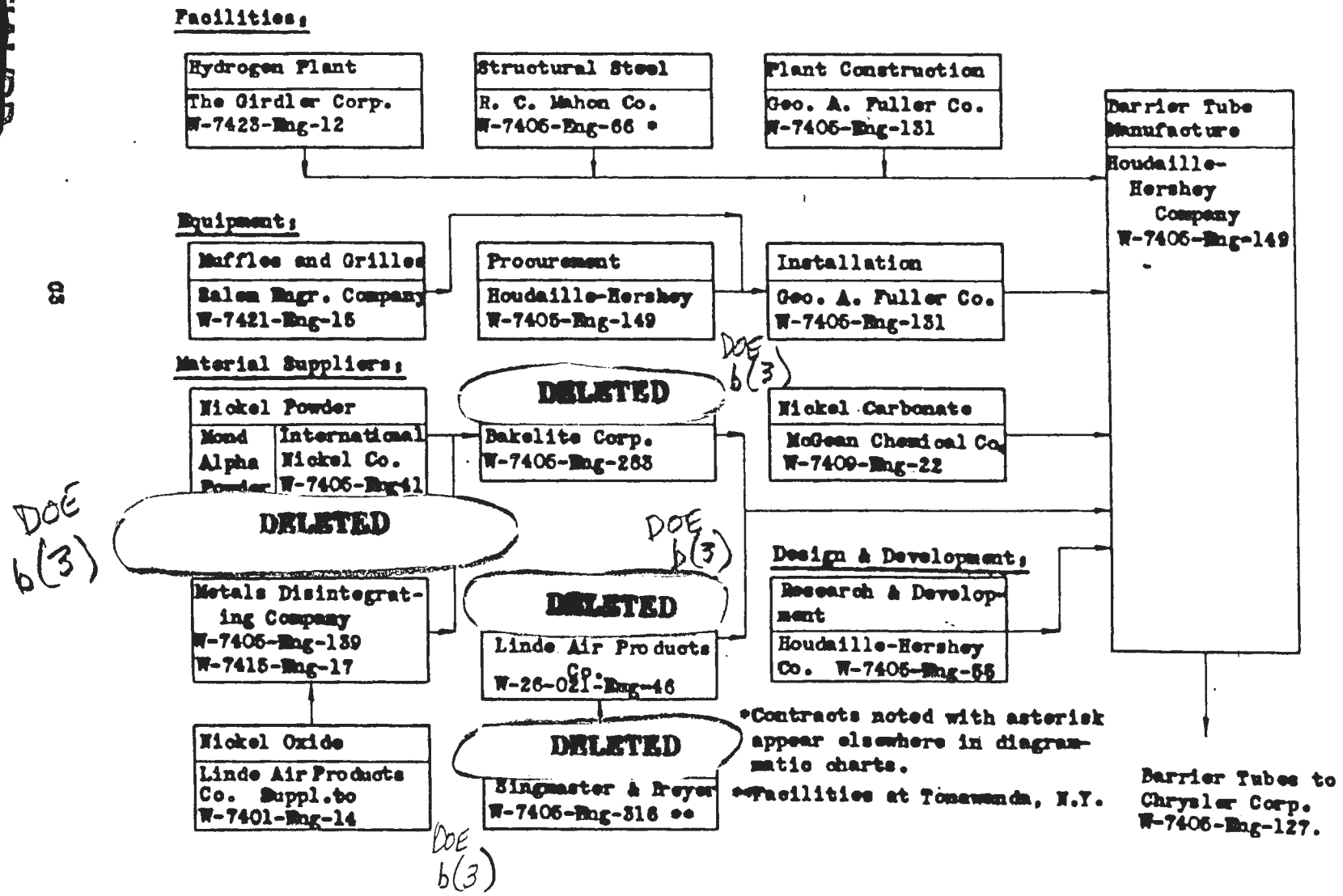
No. 274-O.D.

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NO.	DESCRIPTION	DATE	BY	CHECKED

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BARRIER TUBE PRODUCTION
Decatur, Illinois.



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DESIGN AND ENGINEERING PERSONNEL OF
K-25 CONTRACTORS OTHER
THAN THE KELLEX CORPORATION

Contractor	Product	Estimated Peak
Allis-Chalmers Manufacturing Company	Process Pumps	34
American Locomotive Company	Drums	8
A. O. Smith Company	Coolers	32
Bakelite Corporation	DELETED DOE b(3)	20
Bart Laboratories, Inc.	Pipe plating	5
Beach-Russ Company	Pumps	8
Chrysler Corporation	Diffusers	132
Crane Company	Process valves	9
Farrar and Trefts, Inc.	Nickel clad drums	4
Fisher Governor Company	Butterfly valves	3
F. J. Stokes Company	Pumps	3
General Electric Company	Instrumentation	35
General Electric Company	Motor development	28
General Electric Company	Conditioning furnaces	14
Henry Pratt Company	Butterfly valves	3
Herron-Zimmers Moulding Company	Back strip holders	3
Houdaille-Hershey Corporation	Barrier	234
Midwest Piping and Supply Company	Pipe fabrication	12
National Research Corporation	Scraper cold trap	4
Pacific Pumps, Inc.	Coolant pumps	7
Patterson Kelley Company	Cold traps	4

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MANHATTAN DISTRICT HISTORY

BOOK IV - FILE PROJECT

X-10

VOLUME 6 - OPERATION

"TOP SECRET" APPENDIX

Group 1

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31 December 1946

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MANHATTAN DISTRICT HISTORY

BOOK IV - PILE PROJECT

VOLUME 6 - OPERATIONS

"TOP SECRET" APPENDIX

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5.	Uranium Dissolved and in Waste Storage
6.	Plutonium Production
7.	Unit Costs for Processing Plutonium

SECTION 2 - PRODUCTION ESTIMATES, CODES, & MONTHLY OPERATIONS REPORTS

SECTION 3 - DOCUMENTS

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1. Total Uranium Received

Included in this graph are receipts of such items as billets, extruded rods, unbonded and bonded slugs and machined pieces. In computing the weight of uranium in rods in terms of equivalent metallic billets, a factor of 0.93 has been applied to the weight of rods. Similarly, a factor of 0.83 has been employed in converting from uranium slugs, bonded and unbonded, to rods, or an overall factor of 0.775 in deriving billets from slugs. In converting from machined pieces to billets, a factor of 0.78 has been used.

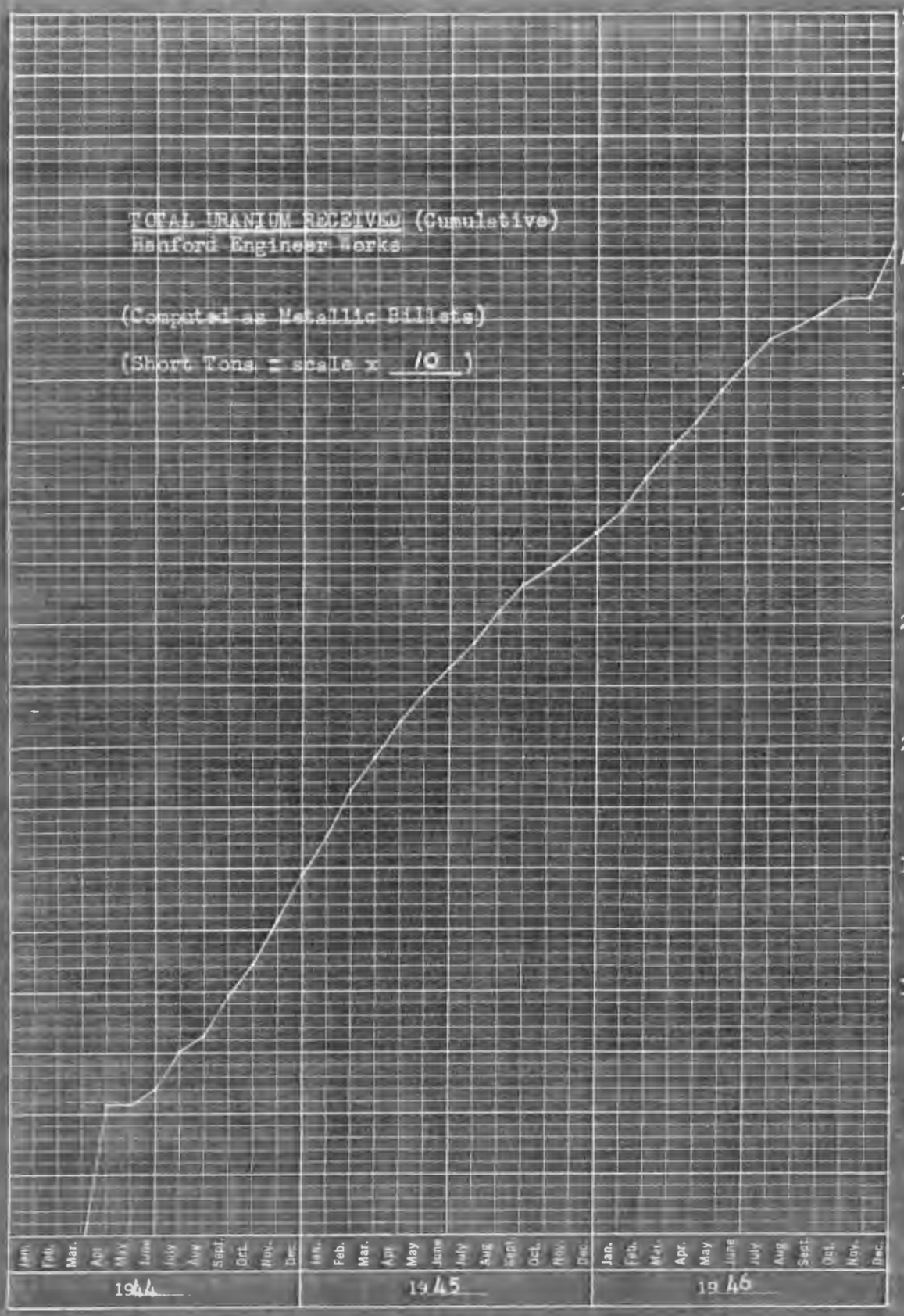

TOTAL URANIUM RECEIVED (Cumulative)
Hanford Engineer Works
(Computed as Metallic Billets)
(Short Tons = scale x 10)
500
450
400
350
300
250
200
150
100
50
0
Jan. Feb. Mar. Apl May June July Aug Sept. Oct. Nov. Dec.
1944
Jan. Feb. Mar. Apl May June July Aug Sept. Oct. Nov. Dec.
1945
Jan. Feb. Mar. Apr. May June July Aug Sept. Oct. Nov. Dec.
1946

Fig. 1

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MANHATTAN DISTRICT HISTORY

BOOK I, GENERAL - VOLUME 4, AUXILIARY ACTIVITIES

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the group except Lt. Collins left Tokyo by air for the United States, arriving at Hamilton Field, California, at 3:00 p.m. on 15 October 1945, after stopovers at Tinian, Kwajalein and Hickam Field, Honolulu.

(References 4, 5, 6.)

6. Itinerary of the Hiroshima Group.

The group headed by Lt. Colonel H. L. Friedell was transferred from Tinian to Guam and thence to Zamboanga in the Philippines, where they awaited transportation by air to Japan. The group was delayed by a series of typhoons and did not enter Hiroshima until about 26 September 1945 (about ten days before the date of departure).

This group spent about one week in Hiroshima and then returned to Tokyo by train, after considerable hardship; there they joined the Nagasaki group and returned with them to the United States.

(Reference 5.)

7. Physical Damage in Hiroshima and Nagasaki.

a. Survey Methods. The surveys of physical damage were made in both cities by the Army Engineers and civilian physicists, who made observations, took photographs and collected specimens and statistics.

The scientists used various ingenious methods to calculate the peak pressures exerted by the atomic blasts at different points, from evidence which was still available. The peak pressures were calculated by Dr. W. G. Penney (British scientist from Los Alamos), from crushed empty vessels, such as oil drums or gasoline cans; from the bending of flag poles, or lightning conductors, away from the blast; and from overturned memorial stones. These pressures were checked against theoretical predictions and further checked against the readings obtained by the measuring instruments which were dropped by parachute at each atomic attack. From these pressure calculations, the

and for a long time after the explosion, as well as the uncertainty regarding the actual population before the bombing, contributed to the difficulties in obtaining reliable information.

b. Estimates of Total Casualties.

(1) The best available figures for the estimated total casualties in each city, as compiled by the Manhattan District, are as follows:

Total Casualties

	Hiroshima		Nagasaki	
	Number	Percent	Number	Percent
Pre-raid Population	255,000	100	195,000	100
Dead	66,000	26	39,000	20
Injured	69,000	27	25,000	13
Total Casualties	135,000	53	64,000	33

(The estimates of the Medical Division of the U. S. Strategic Bombing Survey are higher: In Hiroshima, 80,000 dead and 80,000-100,000 injured; in Nagasaki, 45,000 dead and 50,000-60,000 injured. Reference 13.)

It is generally believed that the energy of the Nagasaki explosion was greater than the energy of the Hiroshima explosion, yet the above figures show that the effects in terms of total casualties were considerably greater in Hiroshima. This was caused not only by the topography and the physical layout of the two cities, but also by unexpected chance circumstances: just previous to the bombing of Hiroshima plans were being made for the evacuation of unnecessary persons, and on the day of the bombing approximately 40,000 extra people had been brought into the center of the town for instructions on these evacuation plans; in Nagasaki, on the other hand, similar evacuation

plans had been carried out a week before the bombing, and the population in the bombed areas had been reduced. Also, many of the families of those working in the mills and plants lived outside of the bombed area. It may be noted that in Nagasaki particularly the numbers of the dead were determined by the numbers of bodies actually incinerated by the clean-up squads and did not include the great number burned in the buildings, whose skeletons were mixed up with the ashes and ruins; nor was there any good count of those refugees who died in the suburbs, particularly in the first few weeks. (References 1, 3.)

(2) The relation of total casualties to the distance from the center of explosion (the point referred to as "X"), in Nagasaki, is shown in the following estimates, based on the casualty figures first obtained by the Manhattan District (Reference 1):

Relation of Total Casualties to Distance from "X".

Distance from "X", feet	Killed	Injured	Missing	Total Casualties	Killed per Square Mile
0-1,640	7,505	960	1,127	9,592	24,700
1,640-3,300	3,688	1,478	1,799	6,965	4,040
3,300-4,900	8,678	17,137	3,597	29,412	5,710
4,900-6,550	221	11,958	28	12,207	125
6,550-9,850	112	9,460	17	9,589	20

(The summation of total casualties in this table, 67,765, was revised by later estimates to 64,000).

(3) There is no way of transposing these figures mathematically to percentages of mortality, because no data have been obtained to show the pre-raid population at the various distances from "X".

A calculation made by the British Mission to Japan, however, based on a preliminary analysis of the study of the Joint Medical Atomic Bomb Investigating Commission, gives the estimated percentages of mortality at other distances, as follows:

Percent Mortality at Various Distances

Distance from "X" in yards	Percent Mortality
500	93%
1,000	66
1,500	37
2,000	18
2,500	6
3,000	1
3,500	0

(From curve, "in Japan", on diagram headed "The More Important Effects of Atomic Bombs on People and Their Homes", in Report of the British Mission to Japan, "The Effects of the Atomic Bombs at Hiroshima and Nagasaki", 1946, page 21.)

Plotting these distances and percentages to suitable scales produces a smooth curve and it is probable that this curve would not be very seriously at variance with the curve which could be produced from the actual facts, if the necessary population figures were available and if proper allowance were made for the layout and topography of the cities and for the large element of chance which inevitably influences the results produced by all explosives. It is common knowledge that freakish results are sometimes the rule rather than the exception in high explosive detonations.

Because of the peculiar psychology of the Japanese who wanted to please the interrogator, one must view with suspicion a good deal of the information gathered by subsequent parties on the location of survivors at the time of the explosion, for the number of unscathed survivors from the center increased with time. Actually the shock of the experience frequently

caused an amnesia in survivors and very few near zero escaped lethal gamma ray exposure.

(4) It was probably inevitable that the great majority of total fatalities should have occurred immediately after the bombing. The causes of many of the deaths could not be definitely determined, and of course many persons near the center of explosion suffered fatal injuries from more than one of the bomb effects. The possible causes of the immediate deaths were, principally, in order of importance: burns, mechanical injury, and gamma radiation, but it seems unlikely that radiation alone would be immediately fatal. Early estimates of the Japanese, for what they may be worth, are shown in the following table (Reference 1):

Causes of Immediate Deaths

City	Cause of Death	Percent of Total
Hiroshima	Burns	60%
	Falling debris	30
	Other	10
Nagasaki	Burns	95%
	Falling debris	9
	Flying glass	7
	Other	7

It is obvious that the percentage figures for Nagasaki include duplications, because the percentages add up to 118, whereas there are no duplications in the figures for Hiroshima. This may account, to some extent, for the wide divergence of the results as estimated for each city, but it is probable that more important reasons for these differences are the variations to local conditions, and the human equation. Different estimators would certainly reach different results in interpreting the evidence for theoretical evaluations of this kind.

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Progress of Radiation Disease

Symptoms in Patients Showing Delayed Effects

Days after Explosion	Most Severe (Patients usually within 1.0 km of center)	Moderately Severe (Between 1.0 and 1.5 km)	Mild (1.5 to 2.5 km)
1.	1. Nausea and vomiting after 1-2 hours lasting 1-2 days.	1. Nausea and vomiting after 1-2 hours lasting 1-2 days.	
2.			
3.			
4.	LATENT PERIOD		
5.	2. Bloody diarrhea and		
6.	3. Vomiting	LATENT PERIOD	
7.	4. Fever		
8.	5. Rapid emaciation		
9.	Death		
10.	(Mortality probably 100%)		
11.		2. Beginning epilation progressing until death	
12.			
13.			LATENT PERIOD
14.			
15.			
16.			
17.			
18.		3. Loss of appetite and general malaise	
19.		4. Fever	1. Epilation
20.		5. Severe inflammation of the mouth and throat	2. Loss of appetite and weakness
21.			3. Temporary sterility
22.			4. Pallor
23.			5. Petechiae (rare)
24.			
25.			6. Moderate emanciation
26.			
27.		6. Pallor	
28.		7. Petechiae, bloody diarrhea, and nose bleeds	7. Secondary infections (Recovery unless complicated by previous poor health or superimposed injuries or infections, except that few, if any, severely epilated persons survived.)
29.			
30.		8. Rapid emaciation	
31.		Death	
.			
.			
.			
45.		(Mortality probably 100% of all showing 5 & 7. Numbers 4 to 8 may be delayed until a few days before death.)	

(References 1, 3.)

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Book I, Volume 4, Chapter 6

APPENDIX

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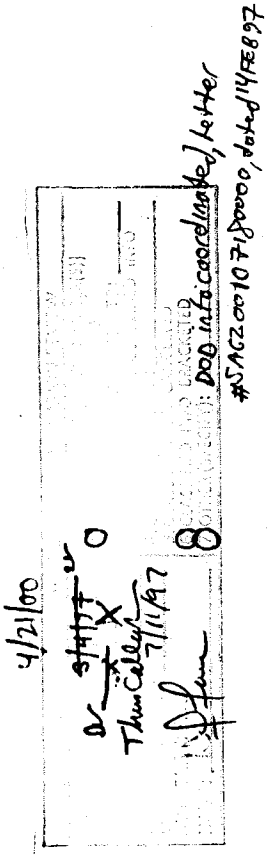
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ENGINEERING AND DELIVERY

Volume 23

Los Alamos Technical Series (3)

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Chapter 6 HISTORY OF PROJECT A AT TINIAN

6.1 Introduction
6.2 Conclusion

Str Wedemeyer?

sively tested at Dahlgren beginning on December 3, 1943.

In September, 1943, the fast-implosion model was proposed by John Von Neumann as an alternative to the slow implosion. As it became clear that this model was a promising one, preliminary planning for converting it into a bomb was begun. A preliminary estimate of 59 inches diameter and 9000-pound weight was made by Von Neumann and Ramsey, and on this basis the Bureau of Standards bomb group was asked to design suitable fairing and stabilizing fins for such a bomb.

OK

In the Fall of 1943 it became apparent that plans for full-scale tests should be started. In view of the critical shortage of B-29's it was first proposed that a British Lancaster be used for the test work, even though a B-29 would almost certainly be used as the combat ship. The Air Force, however, wisely recommended that a B-29 be used for the test work as well, both to avoid non-standard maintenance and to accumulate experience in B-29 operations with such a bomb. In order that the aircraft modifications could begin, Parsons and Ramsey selected two external shapes and weights as representative of the current plans at Site Y (Project Y). One of these was 204 inches long with a maximum diameter of 23 inches and was a model for the current gun assembly. The other was 111 inches long and 59 inches in diameter, corresponding to a fast-implosion assembly. For security reasons, these were called by the Air Force representatives the "Thin Man" and "Fat Man", respectively; the Air Force officers tried to make their phone conversations sound as though they were modifying a plane to carry Roosevelt (the Thin Man) and Churchill

(the Fat Man). Models to these dimensions were ordered from Detroit. Modification of the first B-29 officially began November 29, 1943. Colonel R. C. Wilson was Army Air Forces Project Officer for all aspects of the program, Colonel D. L. Putt at Wright Field was in charge of the division under whose supervision the modification was done, and Captain R. L. Roark was Project Officer in charge of modification.

Tests with the modified aircraft and full-scale dummy bombs were begun at Muroc, California on March 3, 1944. Brode's fuzing group, Bainbridge's instrumentation group, and the delivery group participated in these tests. Coordination of the activities of the different groups in these and subsequent field tests was a responsibility of Ramsey's delivery group. The purpose of the tests was to check the suitability of the fuzing equipment, the stability and ballistic characteristics of the bombs, the facilities then available for field work, and the suitability of the aircraft to carry and drop the bombs. After four weeks of delay, due to torrential rain on the Mojave Desert and aircraft troubles, a series of tests was completed. The negative results of most of these tests thoroughly justified preliminary tests at such an early date. The fuzes proved to be unreliable and, on the basis of these results, an investigation of the possibility of adapting an AFS-13 fighter tail-warning radar to this use was begun. The Thin Man proved to be very stable in its flight, but the Fat Man -- with a tail that the Bureau of Standards bomb group thought would be extremely stable --, proved to wobble badly with its axis departing 20° from the line of flight. Although the B-29 release mechanism worked satis-

factorily for the Fat Man, it failed completely for the Thin Man. Four of the units were bad hang-ups with delays up to 10 seconds, and the final drop was 20 minutes premature while the plane was still climbing to altitude. The bomb in this case fell onto the bomb-bay door which was badly damaged, when the door had to be opened to jettison the bomb. With this accident, the first Muroc tests were brought to an abrupt and spectacular end.

Between the end of the first tests and June 1944, all groups worked to correct the faults demonstrated in the first tests.

DOE b(3)

Detailed designing of this shorter model was begun during this period under the supervision of E. M. McMillan and F. A. Birch. Because of the contrast in dimensions with the Thin Man, this model finally acquired the appropriate name of Little Boy. At the same time the detailed designing of the 1222 form of Fat Man assembly was begun.

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Tests at Muroc were resumed in June, 1944. These tests confirmed previous results in that the first form of fuze being developed

[redacted]

at Michigan was not satisfactory. The first two APS-13's became available to Project Y during the test, and two haywire drop tests (genuine baling wire was actually used) were made with a field adaptation of this equipment to fuzing. The earlier of these provided the first completely satisfactory fuzing test; and, although the second failed, it was probable that the failure was in some of the hastily prepared auxiliary equipment. The Fat Man, its tail assembly modified from the original circular shroud to a square shroud 59 inches on a side, still proved unstable. As a desperate last resort, Captain David Semple, Project Bombardier, suggested a drop be made with internal 45° baffle plates welded into the inside of the shroud as a field modification. To everyone's surprise, this modification was successful, the bomb being completely stable in its flight and the ballistic coefficient being improved rather than decreased as anticipated. No release failures were experienced in the tests.

Adm Ashworth says this was Parsons suggestion. 7/11/78

From the end of these tests until October, 1944 when similar field tests were resumed, a strenuous program of design and procurement was under way at Site Y to obtain units that could be used as components of an actual atomic bomb rather than units that were merely ballistic models. Three basically different models were on hand at this time. One was the Little Boy model of the U^{235} gun assembly, another was the 1222 Fat Man model of implosion assembly, and the third was a model which evolved into the finally adopted 1561 Fat Man implosion assembly. The latter arose from a redesign for the purposes of simplifying the assembly problem (the assembly of 1222 required the insertion of more than 1500 bolts) and of improving

Figure 14

Showing a McDaniel portable neutron counter. The material enclosing the counter tube at the right is 1"-thick polythene.

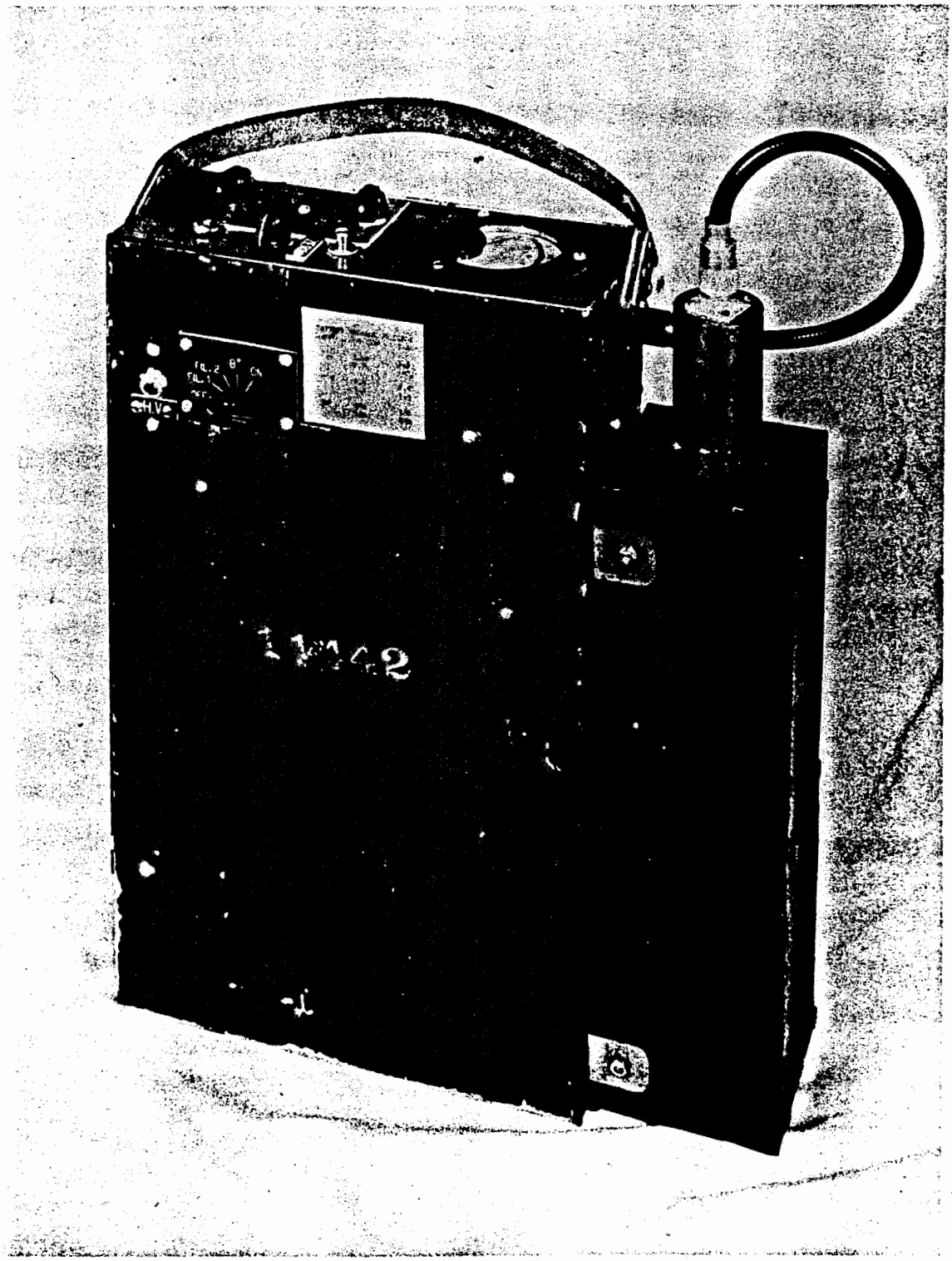


Figure 14

CHAPTER 3

MECHANICAL DESIGN OF MODEL 1561 FAT MAN

A. H. Machen

3.1 INTRODUCTION

This Chapter is concerned with the design of the case, the equipment supports, the lugs, and other external parts of the 1561 model Fat Man. The design of the pit containing the active material for this bomb is discussed in the preceding chapter of this Volume; and the design of the high-explosive components is discussed in Volume XI of the Los Alamos Technical Series.

Figure 1 is an artist's drawing of an early form of the Fat Man model. From that Figure, it can be seen that the model consisted essentially of a large sphere containing the explosives and active material, mounting provisions for auxiliary electronic equipment, an outer armor steel cover, lift lug, and a stabilizing tail assembly. This Chapter will discuss these components of the assembly. A collection of the mechanical drawings of the final form of the 1561 model Fat Man that was used in combat may be found in LA-392.

3.2 DESIGN OF THE SPHERE

Design of the sphere was started with the following specifications:

(1)

(2) A size within the limits of the bomb bay of a B-29

airplane with a fall angle of five degrees;

(3) Provision of detonation holes for more than one detonation pattern.

The first model was the 1222 (Figure 2). Its spherical case was divided by great circles into twelve equal pentagons bolted together by edge flanges; machining these pentagons to a close enough tolerance to permit bolting-up into a complete sphere turned out to be highly impractical.

DOE b(3)

This model was further complicated by a steel case consisting of twenty triangles secured to the sphere by some eleven hundred bolts screwed into holes radially drilled and tapped into the flanges of the pentagon. A steel lift-lug pad, designed to distribute the lug load out into the spherical case, was provided and secured to the sphere at the apex of the top five pentagons.

DOE b(3)

A complete departure from the 1222 pentagon structure was made in the 1291 model (Figure 3) using the same polar cap and belt-band design that was used in the final model. The 1291 model consisted of three spherical zone segments bolted together by 18 bolts screwing into tapped flanges to form a belt section of the sphere. The sphere was completed by two polar caps bolted to the tapped flanges of the belt section.

DOE b(3)

staked into holes drilled in the case for fast, easy mounting of the 110 wire harness clips necessary to hold the coaxial detonator cables (Figure 5).

3.3 MOUNTING OF ELECTRONIC INSTRUMENTS

The mounting of the instruments in the early stages of 1222 design presented few problems. For example, the firing circuit was a small box weighing a few pounds, whereas the final unit was a cast dural tub, weighing about 300 pounds. All of the instruments of this first unit were supported on a single tubular mount attached to the aft side of the sphere (Figure 6), and it was not until after the start of the 1560 model that any of the instruments were placed forward of the sphere. By this time, all the space within the ellipsoidal covers, fore and aft, was occupied by firing and fuzing circuits. The tubular mounting brackets were used fore and aft on the 1222, but discarded on the 1560. A dural cone was designed that would tie into the polar cap bolts, supporting the 300-pound firing circuit box in front and a panel of fuzing instruments aft without danger of vibration. Fast, accurate assembly was kept in mind throughout this design; although the bomb could be a hand-tailored job in most respects, speed was very important in the assembly of the hot model.

A mounting plate was provided for the firing-circuit charging equipment. This plate, mounted in the nose of the front ellipsoid, was accessible through the removable nose plate, and provided a means of battery installation after assembly of the bomb (Figure 7). All instrument plates required constant attention, since changes and rearranging of parts made new layouts necessary to check clearances

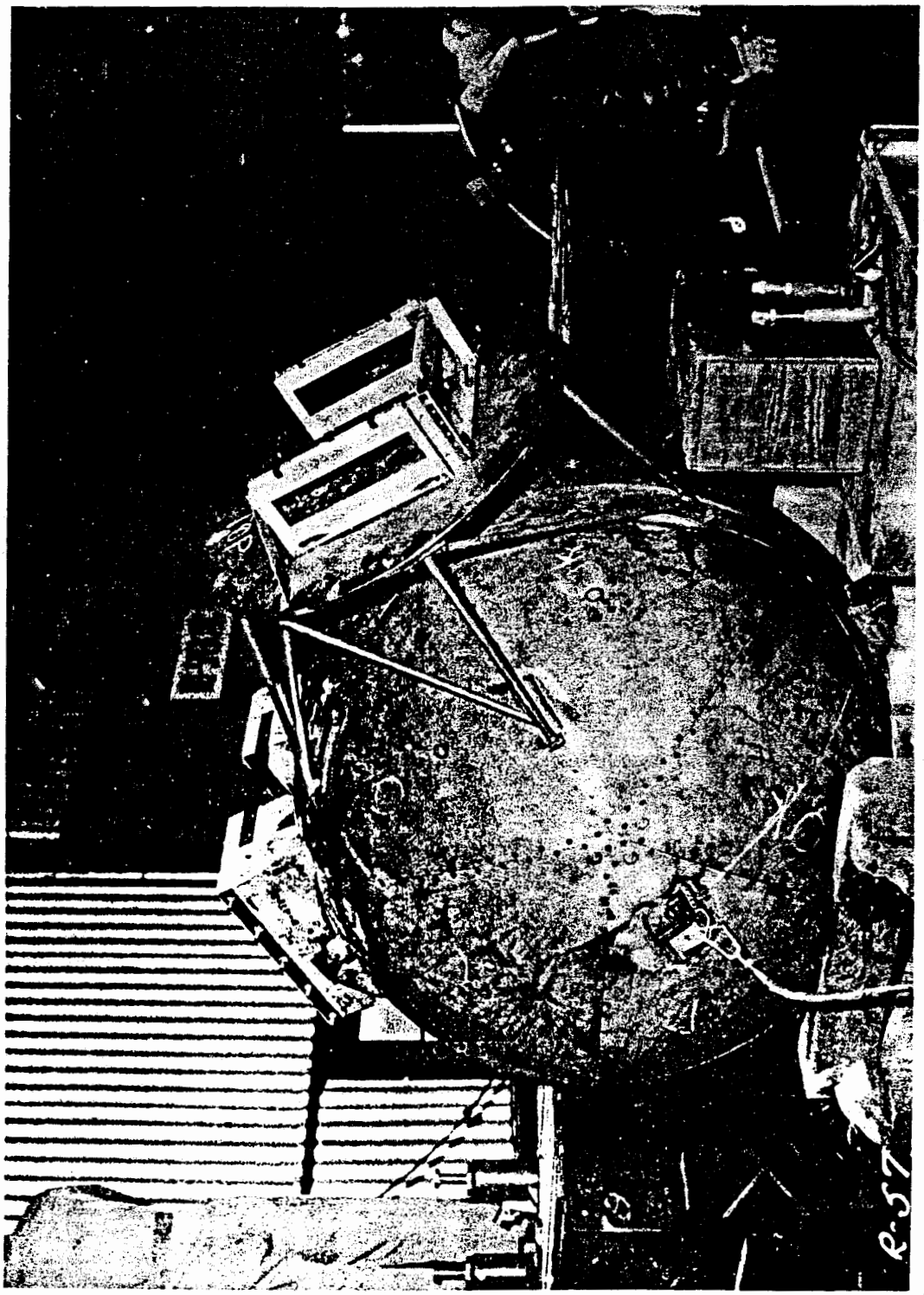


Figure 6

CHAPTER 5

ATOMIC-BOMB PROJECT AIRCRAFT

S. H. Dike

5.1 AIRCRAFT USED FOR ATOMIC-BOMB DELIVERY

The first bomb dropped in connection with this project was released from a TBF at Dahlgren Naval Proving Ground, Virginia, on August 13, 1943. This test, witnessed by N. F. Ramsey, was for ballistic data only. The first drop made in connection with fuze research was made from an SNB-1 (AT-11) at Dahlgren on December 3, 1943.

In the early days, several types of aircraft were considered for carrying the atomic bomb. The shape of the bomb then was very different from either of the two final types. The British Lancaster and our own B-29 were the two planes most seriously considered for the final delivery job. In the early summer of 1943, the B-29 was a new airplane; its performance was still more or less unknown and production rates were not definitely planned.

It was decided in November, 1943, to modify a B-29 at Wright Field for project use. Accordingly B-29 No. 42-6259 was procured. This was the 69th Wichita production airplane.

At that time, there were two distinct types of bombs which Project Y wished to drop. These were known as the "Fat Man" (Figure 1) and the "Thin Man" (Figure 2). The "Thin Man" became obsolete later in the program and evolved into the "Little Boy".

CHAPTER 6

HISTORY OF PROJECT A AT TINIAN

by

N. F. Ramsey

6.1 INTRODUCTION

The Project A organization at Tinian consisted of the following: Officer-in-Charge, Commodore W. S. Parsons USN; Scientific and Technical Deputy to Officer-in-Charge, N. F. Ramsey; Operations Officer and Military Alternate to Officer-in-Charge, Commander F. L. Ashworth, USN; Fat Man Assembly Team headed by Roger S. Warner Jr.; Little Boy Assembly Team headed by Commander Francis A. Birch, USNR; Fuzing Team headed by E. B. Doll; Electrical Detonator Team headed by Lt. Commander E. C. Stevenson, USNR; Pit Team headed by Phillip Morrison and C. P. Baker; Observation Team headed by Luis W. Alvarez and Bernard Waldman; Aircraft Ordnance Team headed by Sheldon H. Dike; and Special Consultants consisting of Robert Serber, W. G. Penney and Captain J. F. Nolan, AUS. The team leaders formed a Project Technical Committee under the chairmanship of Ramsey to coordinate technical matters and to recommend technical actions to Captain Parsons. The following persons were team members:

Agnew, Harold
Anderson, David L., Ensign
Bederson, Ben B., T/5
Bolstad, Milo M.
Brin, Raymond, T/Sgt.
Caleca, Vincent, T/Sgt.
Camac, Morton, T/Sgt.
Carlson, Edward G., T/Sgt.

Collins, Arthur, T/4
Dawson, Robert, T/Sgt.
Fortine, Frank J., T/Sgt.
Goodman, Walter, T/3
Harms, Donald C., T/3
Hopper, J. D., Lt.
Kupferberg, J., T/Sgt.
Johnston, Lawrence H.
Langer, Lawrence M.
Larkin, William J., T/Sgt.
Linschitz, Henry
Machen, Arthur B.
Mastick, Donald, Ensign
Matthews, Robert P., T/3
Miller, Victor A., Lt. (j.g.)
Motechko, L. L., T/3
Murphy, William L., T/Sgt.
Nooker, Eugene L., T/Sgt.
Olmstead, T. H.
O'Keefe, Bernard J., Ensign
Perlman, Ted
Prohs, Wesley R., Ensign
Reynolds, George , Ensign
Russ, Harlow W.
Schreiber, R. E.
Thorton, Gunnar, T/Sgt.
Tucker, J. L., Ensign
Zimmerli, Fred, T/4

Although not strictly members of Project A, the following were closely associated with the work of the Project: Rear Admiral W. R. Purnell, USN, representative of the Atomic Bomb Military Policy Committee; Brig. General T. F. Farrell, representative of Major General L. R. Groves; Colonel E. E. Kirkpatrick, alternate to General Farrell and the Officer in Charge of Construction; Colonel P. W. Tibbets, Commanding Officer of the 509th Composite Group; Lt. Colonel Peer de Silva, Commanding Officer of the First Technical Service Detachment, which served as administrative, security and housing organization for Project A; and Major Charles Begg, Commanding Officer of the First Ordnance Squadron, Special.

Although preliminary construction at Tinian began in April, 1945,

intensified technical activities were not started until July. The first half of July was occupied with establishing and installing all of the technical facilities needed for assembly and test work at Tinian. After completion of these technical preparations, a Little Boy unit was assembled and, with the dropping of unit L1 on July 23, the Tinian base became fully operational for Little Boy tests. In the first test, a dummy Little Boy was fired in the air by radar fuze. Here, as in subsequent Tinian tests, excellent results were obtained. The second Little Boy, Unit L2, was dropped on July 24, and a third, Unit L5, on July 25. The only remaining phase of the Little Boy mission, and included as part of the test, was a check of facilities at Iwo Jima for emergency reloading of the bomb into another aircraft. Since the Iwo Jima facilities were not ready until July 29, this test was postponed until then. On July 29 a completely successful test of the Iwo Jima facilities was completed. The plane landed with the L6 Unit at Tinian so that it could be used in the final rehearsal maneuvers. On July 31 the plane with the L6 took off accompanied by two observation planes. The planes flew to Iwo Jima where a rendezvous was made, and then returned to Tinian where the bomb was dropped and observed to function properly. After the release of the bomb all three aircraft rehearsed the turning maneuvers which would be used in combat. With the completion of this test, all tests preliminary to combat delivery of a Little Boy with active material were completed.

The first Fat Man test, unit F13, was made on August 1, 1945. This unit used cast plaster blocks, electronic fuzing, eight electric detonators, Raytheon detonating unit and informers and smoke puffs

on the operation of the detonators. The test showed that all essential components of the bomb functioned satisfactorily. A second inert Fat Man, F18, similar to F13, was prepared and loaded into a B-29 for drop on August 3. However, due to lack of information at Tinian of the results of the Wendover tests on the adequacy of the venting in the sealed Fat Man, the unit was unloaded and the barometric switches modified so that this information would be obtained on unit F18. In its modified form the F18 unit was dropped on August 5. All components functioned satisfactorily and the venting was adequate for the internal pressure to close a barometric switch set for 17,000 feet pressure altitude 17 seconds before impact. The only remaining preliminary Fat Man test was unit F33, a replica of the active unit, except for the lack of active material and the use of lower quality high explosive lens castings. The components for the F33 unit arrived at Tinian at 1230 on August 2 and preliminary assembly was begun the same day. Although the F33 unit was fully assembled by August 5, it was not dropped until August 8 due to absence of key crews and aircraft on the final Little Boy mission. A test was then conducted as a final rehearsal for the delivery of the first live Fat Man. Both the rehearsal operation and the detonation of the unit were completely satisfactory.

On July 26, the U^{235} projectile for the Little Boy was delivered by the cruiser INDIANAPOLIS. The U^{235} target insert arrived in three separate parts in three, otherwise empty, Air Transport Command C-54's during the evening of July 28 to 29. All three had arrived by 0200 July 29. Since the earliest date previously discussed for combat delivery of the Fat Man was August 5 (at one time the

official date was August 15). Parsons and Ramsey cabled General Groves for permission to drop the first active unit perhaps as early as August 1, with August 2 being more probable since poor weather was forecast for August 1.

Although the active Little Boy unit, No. L11, was completely ready in plenty of time for an August 2 delivery, the weather was unfavorable. The first, second, third, and fourth of August were spent in impatient waiting for good weather. Finally, on the morning of August 5 word was received that the weather should be good on August 6. At 1400 on August 5 General Lemay officially confirmed that the mission would take place on August 6.

The Little Boy was loaded onto its transporting trailer at 1400 on August 5 and, with an accompanying battery of photographers, was taken to the loading pit. The B-29 was backed over the pit at 1500 and the L11 unit loaded shortly thereafter. The aircraft was then taxied to its hard stand where final testing of the unit was completed. By 1800 all was ready. Between then and take-off, the aircraft was under continuous watch both by a military guard and by representatives of the key technical groups.

Final briefing was at 0000 of August 6. Following this, and an early breakfast, the crews assembled at their aircraft. There, amid brilliant floodlights, pictures were taken and retaken by still and motion picture photographers (as though for a Hollywood premiere). For the mission Colonel P. W. Tibbets was pilot of the B-29 (named the Enola Gay) which carried the bomb, Major Thomas Ferebee was bombardier, Captain W. S Parsons was bomb commander, and Lt. Morris Jepson was electronics test officer for the bomb. L. Alvarez,

Bernard Waldman, Harold Agnew and Larry Johnston rode in the accompanying observation aircraft.

The progress of the mission is best described in the log which Captain Parsons kept during the flight:

Captain Parsons' log:

August 6, 1945

0245	Take off
0300	Started final loading of gun
0315	Finished loading
0605	Headed for Empire from Iwo Jima
0730	Red plugs in (these plugs armed the bomb so it would detonate if released)
0741	Started climb Weather report received that weather over primary and tertiary targets was good but not over secondary target.
0838	Leveled off at 32,700 feet 30,750 IA on 31060' True (Nav Log)
0847	All Archies (electronic fuzes) tested to be O.K.
0904	Course west
0909	Target (Hiroshima) in sight
0915 1/2	Dropped bomb (originally scheduled time was 0915) Flash followed by two slaps on plane. Huge cloud.
1000	Still in sight of cloud which must be over 40,000 high
1003	Fighter reported
1041	Lost sight of cloud 363 miles from Hiroshima with the aircraft being 26,000 feet high. 25,960 IA

The crews of the strike and observation aircraft reported that 5 minutes after release a low 3 mile diameter dark grey cloud hung over the center of Hiroshima, out of the center of this a white column of smoke rose to a height of 35,000 feet with the top of the cloud being considerably enlarged.

Four hours after the strike, photo-reconnaissance planes found that most of the city of Hiroshima was still obscured by the cloud created by the explosion although fires could be seen around the edges. The following day excellent pictures were obtained showing the tremendous magnitude of the power of a single atomic bomb, which completely destroyed 60 percent of the city of Hiroshima.

The first Fat Man with active material, unit F31, was originally scheduled for dropping on August 11 local time (at one time the schedule called for August 20). However, by August 7 it became apparent that the schedule could be advanced to August 10. When Parsons and Ramsey proposed this change to Tibbets, he expressed regret that the schedule could not be advanced two days instead of only one since good weather was forecast for August 9 and the five succeeding days were expected to be bad. It was finally agreed that Project A would try to be ready for August 9 provided all concerned understood that the advancement of the date by two full days introduced a large measure of uncertainty into the probability of meeting such a drastically revised schedule. However, all went well with the assembly and by 2200 of August 8 the unit was loaded and fully checked.

The strike plane and two observing planes took off at 0347 local time on August 9. Major C. W. Sweeney was pilot of the strike ship,

Captain K. K. Beahan was bombardier, Commander F. L. Ashworth was bomb Commander, and Lt. Philip Barnes was electronics test Officer. This mission was as eventful as the Hiroshima mission was operationally routine.

Due to bad weather between Tinian and Iwo Jima, a preliminary rendezvous was not planned for three aircraft at Iwo Jima, and instead, the briefed route to the Japanese Empire was from Tinian direct to Yakoshima or Kyushu. The briefed cruising altitude was 17,000 feet. Commander Ashworth's log for the trip is as follows:

Commander Ashworth's log:

0347	Take off
0400	Changed green plugs to red prior to pressurizing
0500	Charged detonator condensers to test leakage. Satisfactory.
0900	Arrived rendezvous point at Yakoshima and circled awaiting accompanying aircraft.
0920	One B-29 sighted and joined in formation
0950	Departed from Yakoshima proceeding to primary target Kokura having failed to rendezvous with second B-29. The weather reports received by radio indicated good weather at Kokura (3/10 low clouds, no intermediate or high clouds, and forecast of improving conditions). The weather reports for Nagasaki were good but increasing cloudiness was forecast. For this reason the primary target was selected.

1044 Arrived initial point and started run on target. Target was obscured by heavy ground haze and smoke. Two additional runs were made hoping that the target might be picked up after closer observation. However, at no time was the aiming point seen. It was then decided to proceed to Nagasaki; approximately 45 minutes spent in the primary target area.

1150 Arrived in Nagasaki target area. Approach to target was entirely by radar. At 1158 the bomb was dropped after a twenty second visual bombing run. The bomb functioned normally in all respects.

1205 Departed for Okinawa after having circled smoke column. Lack of available gasoline caused by an inoperative bomb tank booster pump forced decision to land at Okinawa before returning to Tinian.

1351 Landed at Yontan Field, Okinawa

1706 Departed Okinawa for Tinian

2245 Landed at Tinian

Due to bad weather, good photo-reconnaissance pictures were not obtained until almost a week after the Nagasaki mission. These showed that the bomb detonated somewhat north of the Mitsubishi Steel and Arm Works. All other factories and buildings on the Urakami River from the Nakajima Gawa River through the Mitsubishi Urakami Ordnance Plant were destroyed. The distance from the northernmost factory that was destroyed to the southern boundary of

final disposition of Project A property.

6.2 CONCLUSION

Project A, after a long period of preparation in the United States, had a very short but highly intense and successful period of activity overseas. As in all urgently expedited development projects for which there are no precedents, many mistakes were made in Project A. With the benefit of the experience accumulated by Project A it would subsequently be possible to replan its activities to accomplish its objectives both with greater economy and with improved designs. However, despite the novelty of the weapon and the lack of precedent for most of its problems, Project A did successfully accomplish all of its major objectives and did so on or ahead of schedule.

The object of Project A was to assure the successful combat use of an atomic bomb at the earliest possible date after a field test of an atomic explosion and after the availability of the necessary nuclear material. This object was very effectively accomplished. The first combat bomb was ready for use against the enemy within seventeen days after the first experimental nuclear explosion at Alamogordo and almost all of the intervening time was spent in accumulating additional active material for making an additional bomb. The first atomic bomb was prepared for combat use against the enemy on August 2 within four days of the time of the delivery of all the active material needed for that bomb. Actual combat use was delayed until August 6 only by bad weather over Japan. The second atomic bomb was used in combat three days after the first, despite its being a com-

pletely different model and one much more difficult to assemble. The success of the combat use of the atomic bomb is best summarized by the fact that Japan began surrender negotiations four days after the use of the first atomic bomb.

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Los Alamos, New Mexico

IN REPLY
REFER TO: D-DOC-5099

January 24, 1951

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General Manager
U. S. Atomic Energy Commission
1901 Constitution Avenue, N.W.
Washington 25, D.C.

"When separated from enclosure, handle this document as unclassified (insert proper classification)

Attention: Mrs. J. O'Leary

Dear Mrs. O'Leary:

Enclosed herewith are copies 5,6 and 7,8, of report IA-1161 which are being sent to your office for transmittal to the Division of Military Application for their review after accountability has been established by your office.

We feel that this report is not distributable according to Report M-3679, "Standard Distribution Lists", because it contains weapon data.

Very truly yours,
Helen F. Challenger
Helen F. Challenger
Document Room

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rec. #36268 thru 36271

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OFFICE MEMORANDUM

[redacted] Los Alamos, New Mexico 87545

Distribution DATE: August 2, 1979

This declassified document shows that no beryllium is used in weapons W25, B28, W31, B33, B53, W53 or B61.

A R. D. Baker, ADW

JECT THE LASL POSITION ON FUTURE AVAILABILITY OF BERYLLIUM AND BERYLLIUM OXIDE (U)

SOL ADNSP

STOP 100

The past nine months or so have presented a somewhat perturbing problem for us with respect to the use of beryllium and beryllium oxide in our weapon designs. The variety of opinions and views expressed may have enough of us confused to warrant an explanation of what I believe to be our current position.

The Occupational Safety and Health Administration (OSHA) of the United States Department of Labor (DOL) published, on October 17, 1975, in 40 Federal Register 48814, a "Proposed Occupational Safety and Health Standard for Exposure to Beryllium", which drastically reduced the amount of beryllium products permitted in the air in the workplaces throughout the beryllium industry. This proposed standard was amended twice and was then submitted to the public for comments.

Neither the Department of Energy (DOE) nor the Department of Defense (DOD) was represented at the public hearings on the proposed standard, which were held in Washington in August and September of 1977. The primary beryllium industry was represented, and the difficulties of meeting the proposed standard were pointed out somewhat ineffectively. Briefly, the industry claimed they would be unable to continue production of beryllium (Be) metal and, perhaps, beryllium oxide (BeO). This point was later brought out more emphatically in the press and other media.

In January 1978, the Albuquerque Operations Office (ALO) of the Office of Military Application (MA) of DOE formed a Beryllium Task Group to define the impact of the proposed standard on the Be industry, and to evaluate options available to DOE to minimize the effects of the proposed

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standard. Both KBI and BWI repeatedly informed the DOE/ALO Beryllium Task Group that they cannot meet the proposed new OSHA standard, regardless of how much time, effort, and money they spend; this appears to be questionable. However, even if the industry believed they could meet or closely approach the standard, the small volume of Be metal business does not warrant their investing the necessary amounts of money in new equipment to attempt to meet it. Hence, any such activities would probably require government funding. We now understand that KBI is going to get out of the Be metal business, leaving BWI as the sole source (and in the driver's seat as they pointed out to OMA).

Further he suggests that the government should support research and development programs to find new, nonhazardous, or less-hazardous, processing techniques to produce Be and BeO from the beryllium hydroxide ($Be(OH)_2$) currently produced from the ores by BWI at their Delta, Utah mill. Instituting such techniques in the industry as soon as possible clearly would be a major step toward meeting the proposed standard in the primary beryllium industry, or toward improving the workplace environment even if the standard is not promulgated.

In view of the foregoing, it was deemed worthwhile to state the LASL position on the future availability and uses of Be and BeO. That position follows:

It does not appear that preserving the availability of either beryllium metal (Be) or beryllium oxide (BeO) is mandatory to the Department of Energy (DOE) for the long term, although such preservation may be desirable if it can be achieved by reasonable expenditures of both effort and money. Preserving this availability may well be mandatory, for the short term, to complete production of such current weapons and systems as do utilize these materials, where redesign and testing are impractical.

LASL presently has six weapon types in stockpile (W25, B28, W31, B33, B53, W53) and two entering production (B61-3, B61-4) that contain neither Be nor BeO. We had offered to provide a redesigned W80 without these

materials, pointing out that a complete modification of the production schedule would be required if this option were to to be exercised. We believe that a variation on the W76 could also be provided without these materials. Changes of this nature would require full-scale testing and additional development and production funding. We have informed DOE of such other penalties as might possibly be incurred by eliminating Be and BeO, e.g., possible lower yields, possible greater use of Special Nuclear Materials (SNM), possible greater weight, and probable additional nuclear tests.

Because the Be and BeO availability is uncertain and may remain so for months or even years of hearings and of litigation, we believe that it is extremely important that the nuclear design laboratories design future weapons to use either a minimum of, or no Be and BeO. The DOE/ALO Beryllium Task Group was informed that this is the position of the British Ministry of Defense (MOD). Also, the U. S. Air Force-sponsored Joint Aeronautical Materials Activity Committee (JAMAC) has officially notified Space and Missile Systems Organization (SAMSO) of the Air Force that: "... If beryllium substitutes are available or contemplated, it is strongly urged that their implementation be sought as soon as possible. Unless absolutely necessary, beryllium usage should be avoided in all new systems."

Consistent with the above outlined position, we are working with the Integrated Contractors and within our own materials development organization to perfect and test substitute and alternate materials for the Be and BeO applications in all of our contemplated weapons systems.

We also believe that such beryllium as is determined to be "absolutely necessary" for optimal weapon performance should be ingot-sheet beryllium wherever feasible. The ingot-sheet facility at Rocky Flats could be reconstituted and expanded as necessary, and the design laboratories should attempt to use this material in preference to powder-metallurgy beryllium. There is a substantial quantity of beryllium scrap presently on hand in the DOE complex which could be recycled through Rocky Flats.

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PROGRESS REPORT NUMBER SIX OF THE GADGET PHYSICS DIVISION OF THE LOS ALAMOS PROJECT

JANUARY 15, 1945

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PROGRESS REPORT NUMBER SIX OF THE GADGET PHYSICS DIVISION

OF THE LOS ALAMOS PROJECT

JANUARY 15, 1945

Further assemblies of UH_{10} using U and WC tampers have been made by Group G-1. Criticality has been reached now in BeO, U, and WC and it is found that the observed results are considerably higher than those calculated. The results which for the case of U and WC must be decreased slightly for the effect of the extraneous material on the assembly are as follows: BeO predicted 2.1 kg 25, observed 3.2; U predicted 3.8, observed 6.8; WC predicted 5.1, observed 7.5. A further observation on BeO gave a 5.5 kg of 25 as critical mass when the core was surrounded by Cd. The disagreement between experimental and theoretical results indicates that our understanding of the hydride is far from complete.

In the course of these critical mass experiments, some difficulty was encountered due to changing experimental conditions when additional material was added. Introduction of detecting chambers near the core caused asymmetries which made the effect of added material depend in a rather pronounced way upon its position. Some experience was also obtained with extrapolations to the critical mass using external Geiger counters and internal fission chamber and external long counters. It was found that a fairly good prediction could be made when a long counter was used externally. It seems to be important to eliminate as much extraneous material as possible from the internal assembly. It is, of course, difficult to make measurements with an external detector, and for this

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HISTORY OF THE MARK 4 BOMB (U)

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HISTORY OF THE MARK 4 BOMB (U)

This history recounts the reasons why the Mark 4 Bomb was needed, and tells the story of its design and development in broad outline.

Information Research Division, 3434

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HISTORY OF THE MK 4 BOMB

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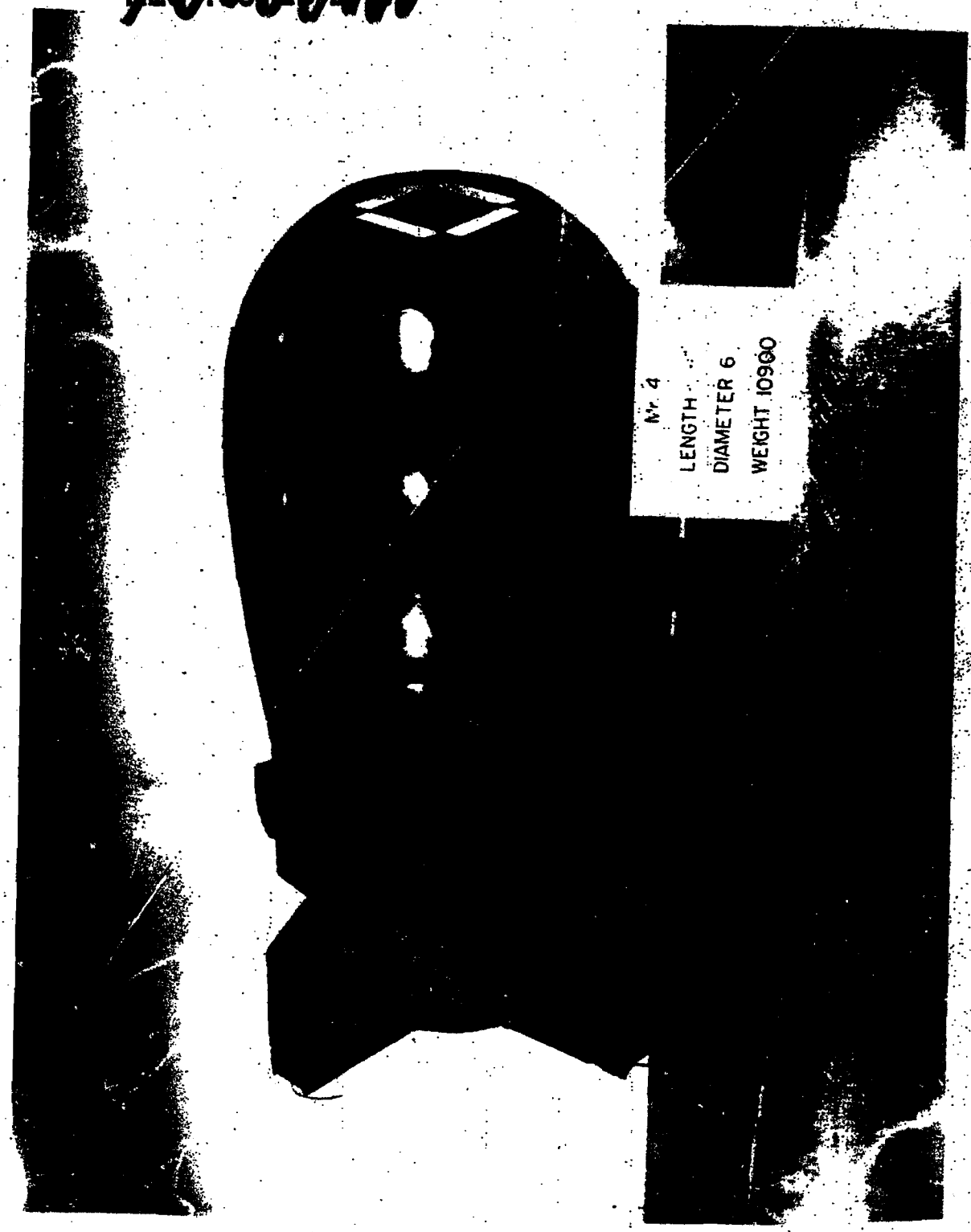


Figure 1. Mk 4 - Exterior View





Figure 2. Comparison of the Shape of Mks III and 4

Figure 4. Nuclear Insertion -- On Ground

An original version of the ground insertion process. The tripod was removed before the bomb was installed in the plane.

(b)(1), (b)(3)

Figure 5. Nuclear Insertion -- Inflight

Inflight insertion version. Baskets to hold the high-explosive sphere segments; arms to hold the nose plate and polar cap.

TIMETABLE OF MK 4 EVENTS

Early 1945	Initial consideration of weapon.
8/2/45	Z Division of the Los Alamos Laboratory organized - Mk 4 development started.
9/27/45	Z-Division representatives started move to Sandia Base.
9/28/45	Issuance of Z-Division progress reports begun.
10/4/45	Mk 4 schedule defined.
12/14/45	Initial practice drop made at the Los Lunas Bombing Range.
7/46	Operation Crossroads at Bikini Atoll - Mk 4 development interrupted.
8/1/46	Atomic Energy Act passed.
2/47	Z Division consolidated at Sandia Base.
4/4/47	First half-scale Mk 4 drops conducted at Salton Sea Test Base.
3/2/48	Sandia Research and Development Board organized.
4/1/48	Z Division becomes Sandia Branch, Los Alamos Scientific Laboratory.
Mid-1948	Operation Sandstone at the Eniwetok Atoll - Mk 4 development delayed.
1/15/49	Mk 4 Preliminary Evaluation Report issued.
3/19/49	Mk 4 weapon enters stockpile.

Chapter I - The Design Task

The Mk 4 weapon was the first atomic bomb to be designed as a practical piece of ordnance as contrasted to a laboratory device that would function properly only when assembled and used by highly trained personnel under closely controlled conditions. The initial approach to this bomb was made early in 1945, shortly after the wartime ordnance designs were frozen. At this time, the implosion-type weapon (which had been initially called the 1561 after its Los Alamos drawing number) had been code-named the Fat Man in recognition of its outer shape, which possessed a distinct midriff bulge. Various designs of the Fat Man were subsequently assigned Mark nomenclature, but there is some question as to the precise definition of either the Mk I or the Mk II designs. The version of the Fat Man that was manufactured and stockpiled after the end of the War (to the basic wartime design) was called the Mk III.[1]

There were several reasons why it was necessary to redesign the Mk III. In addition to the desire to create a practical piece of ordnance--one that could be used in combat by a military team of average training and capabilities--it was hoped to develop better manufacturing and assembly techniques and to clean up marginal ballistic and vibration characteristics, in the interests of improving bombing accuracy. The weapon that eventually evolved from these redesign efforts was for a time called the Mk IV Fat Man, but toward the end of the program the Roman numeral was replaced by the Arabic number 4, and herein we will generally refer to the weapon as the Mk 4.

Initially, consideration was given to design and manufacture of various ballistic or external shapes, investigation of internal pressures within the high-explosive sphere, redesign of detonators for easy installation,

and the proper number of high-explosive lenses for efficient implosion. These studies, at first carried out in different parts of the Los Alamos Laboratory, were consolidated in one organization August 2, 1945, when the Z Division of the Laboratory was created to carry on activities of ordnance design and delivery of atomic bombs. Jerrold Zacharias, who had been active in the radar group of the Massachusetts Institute of Technology Radiation Laboratory, was selected to head this new organization, the Z nomenclature stemming from the first letter of his last name.

The broad area of responsibility of the new Division was indicated in a memorandum dated August 6, 1945, from Dr. Zacharias to J. Robert Oppenheimer, Director of the Los Alamos Laboratory. In part, the memorandum read:

> "With the organization of Z Division in such a fluid state, it is tempting to put nothing on paper. The Division is likely to become larger and to take on so many duties of so many different divisions that a more vertical organization than is usual in Project Y [Los Alamos] will have to be sought."

Dr. Zacharias then proposed an organizational breakdown of the Division, with work assignments as follows:

Z-1, Experimental Systems Engineering, to perform airborne testing, ballistics, aerodynamics, radar, and informer or telemetering work.

Z-2, Assembly Factory and Procurement, to procure, assemble, and ship weapons.

Z-3, Electrical Engineering, to design firing circuits and detonators.

Z-4, Mechanical Engineering for Production, to be concerned with general engineering changes, and--most pertinent to this history--the "coordination of development of streamlined gadget" (i.e., the Mk 4).

Z-5, Electronic Engineering, to handle fuze development.

Chapter II - Early Development

It now became necessary to provide adequate space and facilities for the work of the Z Division. The first step in this direction was taken in the fall of 1945, when the Engineering Division of Los Alamos was requested to design a testing laboratory. This laboratory would simulate on the ground the conditions which bombs and components experienced in flight. This testing laboratory was subsequently built and proved of material assistance in the development of the new weapon.

Meanwhile, a proper work location for the assembly group, Z-2, was being discussed. This organization, which was largely staffed with military and Civil Service personnel, could be administratively separated from the rest of the Division, and required an area convenient to air and rail transportation. A logical spot was the former Oxnard Field, the original Albuquerque Airport (now called Sandia Base), which already was the property of the Manhattan Engineer District, having been obtained in July 1945 for the never-consummated objective of providing space for temporary storage of atomic-bomb materiel during World War II. A meeting was held at Sandia August 29, 1945, at which time it was decided to transfer Z-2 to Sandia Base. It was also decided to remove the W-47 Flight Test Group from Wendover Field, Utah, and bring some of these personnel to Sandia Base.[4] After further discussion, it was decided that weapons production and test activities would be concentrated at Sandia and design work at Los Alamos.[5]

The first Z-Division representatives moved from Los Alamos to Sandia Base September 27, 1945, and on the following day Dr. Zacharias inaugurated the practice of issuing monthly progress reports.[6] The initial report of the Mechanical Engineering Group, Z-4, noted that work on the Fat Man was directed toward making this bomb a more reliable and serviceable weapon--more of a re-engineering task than a radical redesign of the entire gadget.

("Gadget" was a common term in those days for an atomic device.) The report pointed out that the Mk III had to be assembled component by component, while it was hoped that the new bomb could be put together in fairly large subassemblies. In line with this objective, a start had been made in consolidating some of the electrical items into a "cartridge" that could be inserted into the weapon as a unit (in the same manner that a cartridge was inserted in the chamber of a rifle).

A conference between military and Z-Division personnel had meanwhile been held at Wright Field, Ohio, September 21, 1945, to review aircraft capable of carrying the proposed bomb. The B-36 long-range bomber was in the last phases of design and was nearing the flight-test stage, and several jet-propelled medium bombers were being developed. However, the B-36 had a relatively low top speed, and the jet bombers (at that time) were restricted in range, so it was concluded that any immediate redesign of the Fat Man must, of necessity, keep the B-29 in mind as the delivery vehicle.[7]

A Mk 4 planning meeting was held October 4, 1945, at which an optimistic schedule was laid out. The coefficient of expansion of the high-explosive sphere was to be determined by November 1, 1945. The external shape of the bomb and the elements of the firing circuitry were to be settled by December 1, and the sphere assembly and mounting were to be designed by December 15. Drawings of the tail, the cartridge, and the electrical equipment were to be prepared by January 1, 1946. Handling equipment was to be available by February 1; full-scale drops were to be started March 15; a pit and sphere assembly was to be completed by May 15; and the entire bomb was to be ready for stockpile production, with all problems solved, by July 1, 1946. (b)(3)

It is obvious ... that the

estimated date of July 1 for the completed bomb is contingent on the progress made with the pit."[6] However, it was understood that, should the nuclear design be produced, the weapons hardware group was to be ready with the rest of the bomb, and the Z Division swung into high gear.

During design of the wartime Fat Man, there had not been enough time to make a thorough analysis of component functions and their relationships to the overall weapon system. A study was thus started, covering the circuit elements of the bomb and the part played by such factors as simultaneity of switch operation in overall efficiency. Ballistic problems, further described in Chapter III, also were examined. To meet this need, a field-test range was secured, arrangements made for wind-tunnel work, and special telemetry apparatus started into design.

Improvements were made to various elements of the firing system, notably the X-unit, which created the high-voltage surge of current that fired the weapon detonators. The wartime implosion bomb had been equipped with an X-unit whose capacitors were charged to approximately 5600 volts before the bomb was released from the carrying airplane. This not only created a hazard to the bomber crew, but made it necessary to pressurize the X-unit to prevent internal arcing at bomb release altitudes. A safer and simpler X-unit was designed, which was charged after the bomb had fallen to its fuzing altitude, a safe distance from the strike aircraft.

Detonators were modified for easier installation, and much attention was paid to the design of segment molds and the lenses for most efficient implosion of the high-explosive sphere. Extensive tests were made of face pressures between high-explosive segments, and studies were conducted of improved systems of detonator cabling. The protruding Mk III (Yagi) antennas were redesigned to be recessed into the flattened nose of the

bomb, thus simplifying weapon handling. So-called "Dipsy-Doodle" flight tests were conducted to determine the effects of signal interruption on the fuzing and firing system, and minor improvements were made to radar units and to the clock box circuits.[6]

The entire Division compiled lists of needed personnel and prepared plans for anticipated space at Sandia and Los Alamos. Many Division members were military representatives of the Special Engineer Detachment of the Manhattan Engineer District that had been formed to assist Los Alamos scientific personnel during the war, and efforts were made to interest these people in transferring to the Z Division in a civilian capacity.

This acceleration of effort continued for several months, only to be slowed down (in the design area) by many circumstances. One of these was Operation Crossroads, the first postwar full-scale test of atomic bombs. This operation took place at Bikini in July 1946, and many people from the Z Division were assigned in the early months of the year to help with the work. A second factor was loss of supervisory personnel. As an example, Dr. Zacharias returned to the Massachusetts Institute of Technology on September 28, 1945 (to be succeeded by Roger S. Warner, Jr., previously in charge of Z-2B, "Production Schedules and Manuals").[6] This was the first of many such moves, as in the next 15 months, 8 out of 10 Z-Division supervisors were to leave and be similarly replaced. A third item was the loss of trained military personnel as postwar demobilization got under way in early 1946 and career officers were returned to prewar commands. Finally, the lack of specific directives for new bomb design and production, and the general dearth of needed facilities impaired the progress of the overall work.

When the Crossroads contingent returned to the Division in the late summer of 1946, work on the Mk 4 was resumed, although at a somewhat slower pace. The Crossroads test had included an atomic device detonated under water, and the success of this explosion against target ships resulted in a demand for a penetrating weapon. The work on this latter device resulted in manpower being diverted from the Mk 4 program.

The passage of the Atomic Energy Act, August 1, 1946, resulted in cancellation by the Military of plans for Sandia buildings and facilities. The newly created Atomic Energy Commission could not immediately act to counter this cancellation, and securing needed space for the Mk 4 effort was delayed. Supply problems were aggravated as a result of the physical separation of parts of the Division from Los Alamos, with the Z-Division Progress Report of October 1946 noting that daily operations were "continually hampered by an inadequate supply of the common every-day types of electrical equipment ... such things as ordinary rosin solder, hook-up wire, etc."[6]

The need for this new weapon was, however, becoming more apparent, with the Division Leader reporting on November 29, 1946: "As we reach the end of the 1561 FM stockpiling program ... we are finding more and more subassemblies which are marginal .... In certain cases where we have taken steps to bolster one weakness, another develops, and so on ad nauseam until we reach the stage where by physical handling and reworking the component is worn out before it reaches the stockpile .... Because of the low confidence I have in the 1561 gadget, I request the Tech Board to permit me to carry through with the Mk IV test program under forced draft."[8]

Consequently, by early 1947, work was again moving forward and progress could be noted.[9] A full-size Mk 4 prototype shape was built and used in the design of handling equipment. The Z-4 group was moved from Los Alamos to Sandia Base, thus consolidating the entire Division at one location.

Mr. Warner became the AEC's first Director of Engineering and was replaced as head of the Z Division by Robert W. Henderson of Z-4. The Armed Forces Special Weapons Project was created to handle military functions relating to atomic energy, with an office being established on Sandia Base to provide liaison with the Z Division.

A date of March 15, 1948, was agreed to at a meeting of Z-Division supervisors on April 16, 1947, for a "proven Mk IV bomb ready to be procured in quantity by Road." (Road was a general code term for production and stockpiling activities, as the fact that the Division was producing atomic weapons was highly classified.) The meeting report also noted: "A tremendous responsibility has been given to Z Division to have this bomb by the above deadline because either the Mark IV is ready by that date or all work must cease and a new project along different lines must begin." (Official recognition was thus taken of approaching new weapons programs.) All groups were requested to determine their manpower needs and to make a realistic estimate of any additional personnel required, "realizing that even after the people have been found, a 45-day delay for clearance will follow."[10]

New employees subsequently were added to the Division. The cartridge design was completed and started into production. A thorough study was made of the proper location of detonator cabling. The sphere design was completed, and the assembly of the sphere to the outer case was checked out. Investigation was made of barometric switch operation, including the proper location of external ports in the outer case to provide pressure sensing as the bomb fell toward the target. It became necessary to seal the outer case to control this pressure sensing, and different sealing methods were proposed and tested. Handling equipment and storage containers were designed and built.

specifications, was issued January 15, 1949. A crash program produced test and handling equipment for military training and for possible emergency use.[20] As a result of this intensive effort, the first Mk 4 Bomb entered stockpile March 19, 1949.[21]

Field; and to confer with aerodynamicists and ballistics experts. They were informed that the best tail was a design using four equally spaced airfoils, and that these airfoils had to extend some distance out from the body of the bomb since, at high velocities, the air flow broke away from the bomb contour at approximately the maximum diameter of the bomb. It was felt unwise to permit the velocity of the bomb to exceed Mach 1 (the speed of sound), due to buildup of vibration, and it was suggested that a tail shroud be used to retard the rate of fall of the bomb if this velocity was approached in full-scale drops. The use of a blunt rather than a round nose was recommended in an effort to further retard the rate of fall.

A wind-tunnel test program was outlined, to be conducted at Aberdeen. Body shapes without tails would be initially investigated, and the best shapes fitted with simple fins and tested further. If these designs were not completely stable, a circular tail shroud would be added. These wind-tunnel tests would be made at speeds expected to be encountered in actual drops, and stability of the bomb shapes at higher or supersonic speeds would be checked by firing 20-millimeter-diameter models from a gun. It was felt that little could be done to improve the body of the bomb, due to the dimensional limitations imposed by high-explosive sphere and bomb bay, and that efforts should be concentrated on tail modifications.[22]

It had been decided to start full-scale test drops as soon as possible, and an aerial survey of World War II practice ranges in the vicinity of Albuquerque was made September 19, 1945, by members of Z-1. As a result, Range S-1 (which was renamed the Los Lunas Range) was selected for use. This range was located west of the town of Los Lunas and approximately 25 miles southwest of Albuquerque.[23]

In preparation for the work at Los Lunas, recording and communications gear was installed in trailers which could be based at Albuquerque and

less yaw in flight than the standard fin. Fairly consistent performance was also obtained using a thin fin (with a plan area decreased approximately 25 percent) and a circular shroud. Neither of these two types, however, gave completely satisfactory ballistic performance.[27]

Members of the Armed Forces Special Weapons Project suggested that a group of aerodynamicists might be able to suggest improvements in ballistic characteristics, inasmuch as a great deal had recently been learned concerning actions of bodies passing through the transonic region, which had been pierced by manned aircraft only a few months previously. Consequently, representatives of Northrop, Rand, Douglas, North American, Boeing, Wright-Patterson Air Force Base, Inyokern, and Aberdeen formed an advisory panel which initially met May 26 and 27, 1948. The panel suggested that thin fins with flat sides and wedge cross sections would perform better than fins with curved sides and airfoil cross sections. It was also proposed that the planform of the fin be enlarged and drag introduced by the use of plates or spoilers to hold the velocity of the bomb below the transonic range. Arrangements were made to use the Cooperative Wind Tunnel at the California Institute of Technology, which had a greater velocity range than the Aberdeen tunnel.[28]

The flat-sided wedge fins were subsequently tested at the Cooperative Wind Tunnel and exhibited good stability.[22] Consistently good results were obtained from drop tests and, in mid-September 1948, the large-plan wedge fin was tentatively selected for use.[29,30] Detailed results of tests at the Cooperative Wind Tunnel became available October 1, 1948, and confirmed the results noted above. Perforated tail plates were tested on two bombs; one with a square plate and the other circular. The first gave improved control over pitch and yaw, while the second resulted in decreased control--hardly a conclusive test.

Since there was now a limited amount of time and drop tests that could be made, it was decided to concentrate on trials of a large-plan wedge, a thin-fin shroud wedge, a dorsal wedge, and a large plan with a sloping leading edge. All these, it was felt, would have about the same ballistic characteristics. A closer examination of wind-tunnel data subsequently narrowed the choice to a large-plan wedge or a thin-fin shroud wedge. It was then found that the reliability of the thin-fin shroud declined in high-speed, high-altitude drops, whereas the large-plan wedge did not, and the latter design became the obvious choice.

Aberdeen wartime experience with certain experimental bombs had indicated that a "flap" placed at the rear of a bomb shroud (which presented a greater angle of attack to the approaching air than the fin) would help to stabilize bomb flight, and large-plan wedge and thin-fin shroud tails were prepared with this modification. The first to be dropped was the large-plan wedge. One drop showed such excellent flight characteristics--with pitch and yaw of only about 2-1/2 degrees and a ballistic velocity coefficient only slightly lower than that of the thin-fin shroud--that it was deemed advisable to concentrate on further drops of this type, rather than expending time and energy on the thin-fin shroud, which was difficult to fabricate.[22] Accordingly, the large-plan wedge design was frozen for Road production in December 1948.

(b)(1), (b)(3)

More intensive testing in mid-1950 revealed that bomb instability could occur when the Mk 4 was released at altitudes of 26,000 to 31,000 feet, and it was recommended that releases be made above or below this range.[32] It was theorized that this instability was caused by the development of a large shock wave near the fins and the use of circumferential spoiler bands to create smaller shock waves at the mid-point of the bomb and prevent formation of this one large shock wave, was suggested.[33] Tests subsequently made in the Wright Field wind tunnel showed that the Mk 4 shape with five of these spoiler bands possessed good stability.[34] These wind-tunnel tests were the last performed on the Mk 4 weapon, as it was felt more logical to apply the spoiler bands to the approaching Mk 6 Bomb rather than to retrofit them to the Mk 4.[35] As a result, all ballistic testing on the Mk 4 Bomb came to an end.

case. The center "belly band" section was split at the top so that it could be spread apart with assembly tools and slipped over the sphere flanges for positioning over the center section of the sphere. Tension bolts pulled the split-band together at the top. A large rubber gasket sealed the surfaces where the steel case met the aluminum sphere case. The forward case supported the antenna nose plate, which could be removed for access to the sphere. The inflight insertion gear was supported by the forward case. The four fins, which were of aluminum sheet-metal construction, were bolted to the rear case.

(b)(3)

The cartridge structure supported the fuzing components, was cylindrical in shape, and used riveted aluminum sheet-metal construction. The X-unit was bolted to the forward end of this assembly, and the entire unit was

fastened to the bomb sphere case by bolts through the X-unit flange. Shelves and mounting plates were provided in the cartridge structure for installation of fuzing components.

The fuzing and firing system contained the same general components used in the Mk III Mods 1 and 2, but were mounted in a single cartridge structure. The X-unit used the same basic electrical design as that of the Mk III, but was redesigned to reduce size and weight, and to adapt it to the cartridge structure.

The four radar antennas had cavity-backed slot designs and were mounted on a nose plate at the front of the bomb. Being flush with the outer surface of the weapon, these were superior from the aerodynamic and handling standpoints to the Yagi-type antenna used on the Little Boy and Mk III Bombs.

The clock timers and batteries were provided with heated, insulated covers to protect against freezing during flight to the target. These heaters were powered from the aircraft electrical system through a cable connection at the upper surface of the rear case which was separated when the bomb dropped away from the aircraft. This same pullout cable was used during flight to monitor the electrical components in the bomb.

The "Archie" radars were modified APS-13 "Tail Warning Charlie" radars developed during World War II. They were adapted to the bomb fuzing application by using a different antenna system and modifying the range gate. (b)(3)

The early radars required alteration by soldering iron to change the range setting, but later modifications provided plug-in gate lines.

(b)(3)

(b)(1), (b)(3)

The following aircraft were equipped to deliver the Mk 4. For the Air Force; B-29, B-36D, B-36F, B-47B, B-50A, and B-50D. For the Navy; AJ1 and AJ2. Since the Mk 4 was originally designed for carriage by B-29 and similar land-based aircraft, no provision had been made for resisting catapult loads. With the development of Navy aircraft capable of taking off with the bomb from the deck of an aircraft carrier, some difficulty at the sway-brace locations was encountered. This was overcome by redesigning the sway braces in the aircraft bomb bay so as to distribute the load over a sufficient area to prevent damage to the outer case of the Mk 4.

The Mk 4 Mod 0 Bomb entered stockpile March 1949. It was not equipped for inflight nuclear insertion. It included the Type C pit and had an inflatable rubber gasket to seal the ballistic case. Baro ports were located at the nose of the bomb, and the entire interior of the bomb case was used as a "plenum chamber" to provide static pressure to the baroswitches.

The "Mod-Alt" change system was not in use at this time, and major changes were processed under a "block" change system. All weapons in a given "block" of units incorporated the same changes. In May 1950 the Mk-Mod-Alt weapon designation system was instituted, and the weapon was divided into three major assemblies, bomb, fuze, and capsule.[42] The bomb capable of inflight nuclear insertion became the Mk 4 Mod 1

(previously identified as the Block 7 weapon). It also included a solid rubber gasket for sealing the ballistic case. Since it had a Type C pit, the complete bomb nomenclature was Mk 4 Mod 1-C.

The Mk 4 Mod 2-C Bomb incorporated a baro manifold, which was a circular copper tubing assembly installed in the rear ballistic case.[43] Static pressure was provided from intake ports in the rear cover plate through flexible hose leading to the manifold and additional flexible hose connected the manifold to the baroswitches. The accuracy of the baro system was improved by this change, since it no longer depended on a sealed ballistic case for a static pressure source.

The Mk 4 Mod 2-D Bomb incorporated a Type D pit with a higher yield.[44] Special handling equipment was required for insertion of this capsule into the pit, and included a loading tool and a capsule alignment tool or loading trough. By the end of 1951, all Mk 4's had been retrofitted to the Type D pit.[45]

The Mk 4 Mod 3 Bomb incorporated a lightweight magnesium antenna nose plate for easy manual handling. This permitted simplification of the inflight nuclear insertion gear and speeded the operation. Since this change was incorporated on bombs having either the Type C or D pit, it was identified as the Mod 3-C or Mod 3-D.

The "cartridge" became, under the new system, the Mk 4 Mod 1 Fuze. This included the AR-10A "Archie" radars (four required), BS-4 or BS-5 Baroswitches (six required), M-127 "clock" timers (eight required), Mk 4 X-unit, and lead-acid ER-12-10 batteries. The components were mounted on an aluminum structure for convenient installation (b)(3)

interval before supplying power to the firing set. This time interval allowed the airplane to get beyond radar fuzing range, preventing premature detonation by radars ranging off the aircraft. Closing of the arming switches by the clocks allowed current from the 30-volt battery packs to flow through the X-unit choke and the closed firing switch. This current flow caused a magnetic field to be built up in the choke.

At a predetermined altitude, well above the desired burst height, baroswitches closed, allowing the radars to start transmitting and receiving. At the preset burst height, the ranging of any two of the four radars off the target operated a relay network which opened the firing switch in the X-unit. The rapid opening of this firing switch caused a collapse of the magnetic field in the choke, transferring electrical energy to a condenser. When the voltage in the condenser built up to approximately 4000 volts, the spark-gap switch spontaneously broke down, allowing current to flow through the gap and the detonator circuits.

Bridge wires in the detonators were vaporized by the high-voltage pulse. This detonated the explosive material in the detonators, which in turn ignited the high-explosive charges of the sphere, creating a spherically convergent detonation wave which compressed the nuclear components to supercriticality.

(b)(1), (b)(3)

Chapter V - Mk 4 Improvement

After the Mk 4 entered stockpile, design improvements continued despite the fact that much of the engineering staff was transferred to work on other weapons. A list of desirable modifications was compiled, based on a joint military-Sandia survey, and, after thorough review, was formally issued May 18, 1949, under the title "Desired Military and Technical Characteristics of FM Type Atomic Weapons."[48]

Five areas were listed, including weapon battery, ballistics, inflight nuclear insertion and extraction, lightweight case, and improved fuzing system. Battery improvement, due to the state of the art, was deferred for later consideration; the ballistics story has been developed in Chapter III.

The inflight nuclear insertion and extraction project was already well under way, as studies had started in early 1948, (b)(3)

Facilities for supporting the antenna nose plate and sphere access door while the nuclear capsule was being guided into position were also provided. This support device was temporarily bolted to the nose of the bomb while it was in the bomb bay of the aircraft proceeding to target, and was manually operated.[18] A later production version eliminated the support arms for the nose plate and access door, which by that time had been much reduced in weight.

This topic was mentioned in the September 30, 1948, meeting of the Sandia Research and Development Board, with Sandia pointing out that the change would necessitate a major change in material sources, tooling, and bomb handling equipment, and that a thorough stress analysis would be required.

Subsequently, considerable correspondence on the subject developed between the Division of Military Application, Military Liaison Committee, AEC, and Sandia, with efforts being made to determine whether or not there was a real need for the heavy case for either flak protection or storage.[53,54,55,56] On December 24, 1948, Sandia informed AEC that a development program for reduction of Mk 4 Bomb weight had been established at Project Roger (the Army's Rock Island Arsenal, which was handling certain weapons production work) and its subcontractor, the American Car and Foundry Company. The purpose of this program was to evaluate and recommend weight reductions based on an aluminum outer case produced by the same tools used for forming the steel casing.[57]

Meanwhile, various pressures were exerted both for and against the design of a lightweight case,[58,59,60] with the matter being decided February 17, 1949, when the Division of Military Application directed Sandia to subcontract the design of an aluminum case.[61] On March 16, Northrop Aircraft, Inc., was invited to design a riveted case,[62] and in May the American Car and Foundry Company was asked to design a welded case.

Ballistic testing of both the riveted and welded cases was conducted in December 1949, and static and dynamic tests were run at Wright Field.[63] These proved that both cases were satisfactory, and, inasmuch as cost and weight comparisons were roughly equivalent, it was decided to procure both types.[64,65,66,67] Production of the riveted design was turned over to Project Royal (the AEC manufacturing facility at Kansas City), and the

(b)(1), (b)(3)

Meanwhile, it was becoming evident that the lightweight case and the improved fuze could be put into production simultaneously, and in July 1950 a high-priority or "crash" program called 4-N was established.(b)(3)

Shortly thereafter, however, it was decided to treat the modified Mk 4 as an entirely new weapon, and the program evolved into the Mk 6.

Design attention was also given to improving the pressure-operated or barometric switch which "armed" or placed the radar in operational condition. The original approach had been to consider the interior of the bomb as a plenum or pressure chamber and to measure the pressure as the bomb fell through the air toward the target. Vent holes to the external atmosphere were located in the nose of the bomb, and it became necessary to provide an airtight seal between the sections of the bomb case.

It was at first thought that an inflatable rubber tube would serve for this seal,[74] but it was found impossible to maintain air pressure in this tube. In addition, the relatively large volume of the plenum chamber made it difficult to secure rapid responses to changes in external air density, and it was decided to substitute a small-volume manifold constructed from a length of tubing bent into a circular shape and installed under the contour of the bomb skin near the tail. Because of the possibility of the nose ports becoming plugged with ice,[75] they were relocated in the tail plate.[76]

UNCLASSIFIED

Implosion-Type Bomb -- A weapon based on the principle discovered by Professor Charles E. Munroe, Washington, D. C. Written up by him in Scribner's Magazine and the American Journal of Science in 1888 and in Popular Science Monthly in 1900. Rediscovered by Egon Neuman of Germany, who secured German and English patents in 1910-11. The Munroe principle notes that an increased explosive effect is created when an unconfined cylinder of high explosive is hollowed out. In 1920 the Journal of the Society of Chemical Industry (London) stated that "no practical use has apparently been made of this discovery." Suggested by S. H. Neddermeyer at Los Alamos as a means for producing the extremely high pressures required on the capsule of an atomic bomb. Not much attention was paid to the suggestion until it received the backing of John von Neumann and George Kistiakowsky. The same principle was used in the Pacific area in World War II as a means of destroying Japanese pillboxes, and for increasing the penetrating effect of rockets.

Kiloton Yield -- A means of measuring the effect of a nuclear explosion by comparing it with the effect of an explosion of TNT. One-kiloton yield is equivalent to the effect of 1000 tons of high explosive.

Kirtland Field -- An Air Force Base located in Albuquerque, New Mexico, and using part of the facilities of the Municipal Airport (Sunport). Kirtland Field was built in 1939 with the help of federal funds. Named for Colonel Roy F. Kirtland, one of the earliest Army aviators.

(b)(3)

UNCLASSIFIED

Manhattan Engineer District -- A district of the Army Corps of Engineers established in August 1942 under the command of General Leslie R. Groves to develop weapons using atomic energy.

Military Liaison Committee -- A committee established by the Atomic Energy Act of 1946 to advise and consult with the AEC and on behalf of the Department of Defense, on all atomic-energy matters relating to military applications of atomic weapons. Chairman can be any active or retired officer of the Armed Forces. Includes a representative or representatives from each Department of the Armed Forces.

Operation Crossroads -- See Crossroads.

Operation Greenhouse -- See Greenhouse.

Operation Sandstone -- See Sandstone.

Oxnard Field -- Constructed in 1929 as the airport for the City of Albuquerque by Frank G. Speakman. Named Oxnard Field in 1931 for James G. Oxnard, who financed its expansion and who was its owner until May 1942, when the area was taken over by the Government for an Air Depot Training Station.
(b)(3)

Radars -- See Archies. Named for RAdio Detecting And Ranging.

Salton Sea Test Base -- Located on the site of a Naval Auxiliary Air Station on the shores of Salton Sea, California. Acquired in June 1946 for ballistic tests of the Z Division.

Sandia Base -- Located east of the City of Albuquerque and adjoining Kirtland Field. Encompasses the area formerly occupied by Oxnard Field, plus additional land extending south to the Isleta Indian Reservation and east to the Manzano Mountains. Operated under the tripartite control of the Armed Forces Special Weapons Project.

Sandia Laboratory -- An outgrowth of the Los Alamos Laboratory's Z Division. Originally established as Sandia Branch of LASL; in November 1949 it became an independent entity, Sandia Corporation, with a contract with the AEC and under the managerial direction of the Western Electric Company.

Sandia Research and Development Board -- A joint Sandia Laboratory-military board formed at Sandia Base to provide local guidance on weapons design.

Sandstone -- Full-scale test operation held in the Pacific in April 1948.

Tactical and Technical Liaison Committee -- A committee of Air Force officers established to provide liaison between the atomic project and the Air Force prior to admittance of the Air Force as a member of the Armed Forces Special Weapons Project.

Telemetry -- The science of radio transmission of information to a ground station from an object traveling in space.

Wendover Field -- Located in Utah, west of Salt Lake City. A training location for the Army Air Forces work with wartime atomic bombs.

W-47 Flight Test Group -- The Army Air Forces group stationed at Wendover Field during World War II. Part of this group was transferred to Kirtland Field after the war and helped in the bomb drops at Los Lunas.

Yagi -- A radar antenna developed by a Japanese scientist.

X-Unit -- ~~A high-voltage transformer~~ A device used to provide high voltage to the weapon detonators.

Z Division -- A Los Alamos Laboratory division established in July 1945 to handle development work on atomic bombs. Part of the Z Division was moved to Sandia Base at the close of the war, and became the nucleus of Sandia Laboratory. Named for Jerrold Zacharias, first leader of the Division.

6-1-51	Mk 5 Mod 0 released for production and stockpiling.
11-52	Mk 5 Mod 1 stockpiled.
6-54	Mk 5 Mod 2 stockpiled.
1-55	Mk 5 Mod 3 stockpiled.

HISTORY OF THE MK 5 BOMB

The feasibility of creating a small implosion bomb was one of the weapon concepts studied by the Los Alamos Scientific Laboratory after the end of World War II. The over-all size of the wartime Fat Man device (which was to be as large as possible) had been established by the dimensions of the B-29 bomb bay and the existing state of implosion theory, and the resulting weapon was a bomb with reasonably high nuclear efficiency, but which was difficult to handle due to its bulk and weight (60-inch diameter; 128-inch length; 10,900-pound weight). Consequently, calculations were made of compressions produced by small-diameter high-explosive spheres, and different arrangements of nuclear material were studied.

This small implosion design was of interest to the Military, and the Military Liaison Committee informed the Atomic Energy Commission October 31, 1947, that current implosion bombs did not lend themselves to wide or flexible employment, and that a weapon both lighter and smaller than the Mk 4 (then in design) would be of considerable military importance.[1] The Atomic Energy Commission, in replying to this letter on December 10, 1947, pledged support of a vigorous program to develop a small bomb.[2]

Meanwhile the Division of Military Application wrote to Santa Fe Operations Office November 25, 1947, noting that any reduction in bomb weight would result in an increased range of the carrying aircraft and pointed out that: "Reduced dimensions might open up an entire new field of flexibility in the employment which could be a decisive influence in the military capability of getting the bombs home in war." However, it was noted that the Los Alamos effort on Operation Sandstone (to be held in the Pacific during the summer of 1948 to test new nuclear designs) might delay starting work on the new weapon.[3]

During 1948, it became apparent that determination of size, shape and weight for the lighter and smaller weapon required an understanding of military aircraft, delivery plans and problems. A conference was consequently held at Los Alamos September 2 and 3, 1948, which was attended by representatives of the Military, AEC weapon laboratories, and cleared members of the aircraft industry. It was decided that a bomb with a diameter of 40 to 48 inches and weighing between 5000 and 6000 pounds would cause significant improvement in aircraft performance and increase the probability of successful weapon delivery. It was felt that the length of the weapon should be retained at 128 inches.[4]

(b)(1), (b)(3)

During the foregoing study period, the project had been known as the Small Weapon Program and was directed by the Los Alamos Committee for Weapon Development. It was subsequently transferred, October 11, 1948, to the W (Weapon Development) Division of Los Alamos with the request that this Division undertake an "experimental, calculational, and fabrication program aimed at the production of a specific model of a complete small weapon for test early in 1951."[6]

(b)(1), (b)(3)

The work of the W Division almost immediately involved the Sandia Branch of the Los Alamos Scientific Laboratory and, it was suggested that a Steering Committee be established to direct development work on the weapon.[7] This new group initially met November 3, 1948, and the Chairman noted that much confusion had previously arisen due to various terms used to identify a given weapon, and suggested that a standard weapon name as well as a designation for the Steering Committee be established.[8] Mk IV nomenclature had already been assigned, so it was logical to use the next number, Mk V, for this device. The Committee felt, however, that development models of the weapon should be specifically identified, and it was decided to use the letter "X" as a prefix to show the experimental nature of the design. It was also decided to add the letter "T" to indicate--in the phraseology of the Committee's minutes--"the word 'tentative' or 'tiny' (or something)." Thus the weapon became known as TX-V (and, soon thereafter, the TX-5) and the Committee as the TX-5 Steering Committee. The adoption of this system set the pattern for many subsequent atomic devices.[9]

(b)(1), (b)(3)

(b)(1), (b)(3)

The possibilities of contact or even subsurface burst requirements were briefly considered, but it was felt that the basic design of an implosion weapon made anything but air burst impossible.

(b)(1), (b)(3)

Computer time was scheduled, and it was hoped to have compression figures in about 3 months.[10] (Subsequently, due to the pressure of other computer programs, it was decided to interpolate, using other computational results.) The Steering Committee established a schedule calling for preliminary design by January 1, 1950, and complete design July 1, 1950. (b)(3)

The contents of a December 10, 1948, letter from the AEC General Advisory Committee were discussed in the January 7, 1949, meeting of the TX-5 Steering Committee. This letter stated that reduction of size and weight of atomic weapons was vitally important to national defense and that the AEC wholeheartedly supported the aims of the Steering Committee in this regard. The Advisory Committee hoped that the new small weapon could be ready for production soon after proof-firing, and suggested that a substantial portion of the implosion stockpile in early 1950 be made up of the new bomb. The program was accordingly accelerated.[12]

Problems of nuclear safing had meanwhile been studied. The Sandia Research and Development Board (later renamed Sandia Weapons Development Board and, still later, Special Weapons Development Board) was a group including representatives from Sandia and the Armed Forces Special Weapons Project, the military organization formed to handle military problems connected with the atomic bomb. The Board held an initial meeting March 2, 1948, and suggested that design attention be paid to the possibility of extracting

the nuclear capsule of an atomic bomb while it was being carried to the target. This action would prevent nuclear detonations caused by a landing accident, should the mission be aborted or the plane return to base with weapon unexpended.[13]

The Tactical and Technical Liaison Committee, established by the Air Force to provide atomic liaison, had suggested, March 26, 1948, that both extraction and insertion in flight would increase aircraft and airport safety, and reduce nuclear contamination caused by accidents during takeoffs or landings.[14] (b)(3)

(b)(1), (b)(3)

(b)(3)

The next step was to design some type of capsule handling device, and this became known as an inflight insertion mechanism. The device initially was manually operated, but this operation was awkward due to lack of room in the bomb bay, and the fact that the aircraft had to fly at low altitudes during insertion or extraction. (The bomb bay was not pressurized, and personnel operating the equipment would have been handicapped if required to wear oxygen masks.) An automatic and remotely controlled mechanism was accordingly designed.

Consideration was given to the necessity for duplicate bridge wires in each detonator. (b)(1), (b)(3)

The use of single bridge wires was then proposed, with two X-units connected in parallel to each bridge wire. This raised the question as to whether one X-unit would fire back through the other, rather than across the bridge wires, and it was eventually decided to provide one highly reliable X-unit and to use single bridge wires.

Initial Sandia mention of the new weapon was made in a progress report of February 18, 1949, wherein it was noted that SLE-7 had been organized as the FM Mk V Division.[18] This Division, in starting design work, was confronted with the general shortage of office and engineering space and facilities at Sandia, caused by the concurrent startup or expansion of other design projects.

Selection of aircraft to carry the TX-5 was discussed in the Steering Committee meeting April 8, 1949. The Air Force program was currently slanted toward use of heavy, long-range bombardment aircraft. Medium-size Navy bombers were still under design, and would not be in production for at least 2 years. Consequently, there was some feeling that current schedules might produce a new bomb before a suitable bomber became available.[19]

As a result of the above meeting, a TX-5 Ad Hoc Panel was appointed by the Military Lisison Committee May 12, 1949.[20] (b)(1), (b)(3)

It was agreed that as small a diameter as practicable should be selected, since it would be relatively

"The TX-5 project is one of the weapon developments in which the interest of the Atomic Energy Commission reflects a general concern that within the next few years the problem of successful delivery of atomic weapons may come to overshadow the problem of increasing the destructive potential of the weapons themselves. The Commission recognizes the primary responsibility of the using forces to set forth desired technical characteristics of weapons, as these characteristics bear on the delivery problem. The Commission remains anxious, however, that its best technical effort be contributed to a solution of this problem in all of its variants which impinge in the area of the Commission's responsibility. The Commission will therefore continue to keep you fully informed of prospective reductions in weapon size and weight, hoping that full advantage will be taken of these forecasts to ease the problems of development of future carriers, a field in which the development cycle is of course substantially longer than the usual cycle of development of the associated weapons."[22]

The Military Liaison Committee wrote to the Division of Military Application February 9, 1950, noting their belief that large-implosion-bomb performance could be considerably improved through use of nuclear design improvements produced by the TX-5 work, and stating that the smaller bomb should be reserved for use in guided missiles. The Committee proposed that a decision on TX-5 production be made after the 1951 tests, and stated that it appeared inadvisable at this time to freeze design on a production TX-5 or to plan for any substantial stockpiling.[23] The Division of Military Application stated, in a reply dated March 30, 1950, that the TX-5 nuclear design improvements might obviate any need for larger bombs, but agreed that higher priority would be assigned to use of the TX-5 with future guided missiles.[24]

The cumulative effect of the above correspondence might have redirected the TX-5 program, if the international situation had not intervened. The increasing pressures of the cold war and eventual outbreak of the Korean conflict caused an acceleration of national defense plans and programs, and resulted in a May 10, 1950, visit to Los Alamos by the Director of the Division of Military Application. This visit was discussed in the May 26, 1950, meeting of the TX-5 Steering Committee, in which it was noted that it would be necessary to "pick up a few months or even a year" in TX-5 production.[25] Subsequently, a teletype was received July 11, 1950, from Washington AEC which, in part, stated: "Anticipating a Military requirement not yet firm you are directed to formulate a plan using all facilities at your disposal to deliver to War Reserve at the earliest possible date service models of TX-5."[26]

The schedule that Sandia subsequently prepared established a target date of January 1, 1952, for Mk 5 production. Quantity requirements were authorized in a Military Liaison Committee directive of September 14, 1950, and these figures were revised upward December 18. The Atomic Energy Commission urged all possible speed and noted that:

> "Certain procedures may be warranted at this time that would otherwise not be undertaken until the weapon characteristics were more completely defined. There is an obligation on us all to economize in both effort and money by identifying promptly the areas of uncertainty and pressing for their resolution. There is an equal obligation, however, to take action as necessary to maintain the best possible schedule, even at the risk of occasionally involving ourselves in unproductive ventures."[27]

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HISTORY OF THE MARK 4 BOMB (U)

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Figure 2. Comparison of Shape of Mks III and 4

and the proper number of high-explosive lenses for efficient implosion. These studies, at first carried out in different parts of the Los Alamos Laboratory, were consolidated in one organization August 2, 1945, when the Z Division of the Laboratory was created to carry on activities of ordnance design and delivery of atomic bombs. Jerrold Zacharias, who had been active in the radar group of the Massachusetts Institute of Technology Radiation Laboratory, was selected to head this new organization, the Z nomenclature stemming from the first letter of his last name.

The broad area of responsibility of the new Division was indicated in a memorandum dated August 6, 1945, from Dr. Zacharias to J. Robert Oppenheimer, Director of the Los Alamos Laboratory. In part, the memorandum read:

> "With the organization of Z Division in such a fluid state, it is tempting to put nothing on paper. The Division is likely to become larger and to take on so many duties of so many different divisions that a more vertical organization than is usual in Project Y [Los Alamos] will have to be sought."

Dr. Zacharias then proposed an organizational breakdown of the Division, with work assignments as follows:

Z-1, Experimental Systems Engineering, to perform airborne testing, ballistics, aerodynamics, radar, and informer or telemetering work.

Z-2, Assembly Factory and Procurement, to procure, assemble, and ship weapons.

Z-3, Electrical Engineering, to design firing circuits and detonators.

Z-4, Mechanical Engineering for Production, to be concerned with general engineering changes, and--most pertinent to this history--the "coordination of development of streamlined gadget" (i.e., the Mk 4).

Z-5, Electronic Engineering, to handle fuze development.

Dr. Zacharias predicted that some of these groups would move to Sandia, but that the engineering people would probably remain at Los Alamos.[2]

On August 8, 1945, the day before the first--and also last--Fat Man weapon ever to be used in combat was detonated over the Japanese city of Nagasaki, a memorandum was released which outlined the Fat Man design problems in considerable detail, pointing out that it was necessary "to simplify and render more reproducible assembly of FM, to improve ballistics of FM, to incorporate simplification and developments of the individual components." Mandatory requirements were to maintain the ability to monitor the weapon battery and electrical system while the weapon was being carried to the target and to keep the weapon small enough to fit into the B-29 bomb bay. Desirable objectives were to provide rapid bomb assembly, permit testing and inspection without disturbing component parts, allow shipment of a practically complete weapon (less detonators and nuclear material), provide armor to protect the bomb against shrapnel, and maintain dry air within the weapon.[3] Thus, the design task was defined and the stage set for development work.

Chapter II - Early Development

It now became necessary to provide adequate space and facilities for the work of the Z Division. The first step in this direction was taken in the fall of 1945, when the Engineering Division of Los Alamos was requested to design a testing laboratory. This laboratory would simulate on the ground the conditions which bombs and components experienced in flight. This testing laboratory was subsequently built and proved of material assistance in the development of the new weapon.

Meanwhile, a proper work location for the assembly group, Z-2, was being discussed. This organization, which was largely staffed with military and Civil Service personnel, could be administratively separated from the rest of the Division, and required an area convenient to air and rail transportation. A logical spot was the former Oxnard Field, the original Albuquerque Airport (now called Sandia Base), which already was the property of the Manhattan Engineer District, having been obtained in July 1945 for the never-consummated objective of providing space for temporary storage of atomic-bomb materiel during World War II. A meeting was held at Sandia August 29, 1945, at which time it was decided to transfer Z-2 to Sandia Base. It was also decided to remove the W-47 Flight Test Group from Wendover Field, Utah, and bring some of these personnel to Sandia Base.[4] After further discussion, it was decided that weapons production and test activities would be concentrated at Sandia and design work at Los Alamos.[5]

The first Z-Division representatives moved from Los Alamos to Sandia Base September 27, 1945, and on the following day Dr. Zacharias inaugurated the practice of issuing monthly progress reports.[6] The initial report of the Mechanical Engineering Group, Z-4, noted that work on the Fat Man was directed toward making this bomb a more reliable and serviceable weapon--more of a re-engineering task than a radical redesign of the entire gadget.

("Gadget" was a common term in those days for an atomic device.) The report pointed out that the Mk III had to be assembled component by component, while it was hoped that the new bomb could be put together in fairly large subassemblies. In line with this objective, a start had been made in consolidating some of the electrical items into a "cartridge" that could be inserted into the weapon as a unit (in the same manner that a cartridge was inserted in the chamber of a rifle).

A conference between military and Z-Division personnel had meanwhile been held at Wright Field, Ohio, September 21, 1945, to review aircraft capable of carrying the proposed bomb. The B-36 long-range bomber was in the last phases of design and was nearing the flight-test stage, and several jet-propelled medium bombers were being developed. However, the B-36 had a relatively low top speed, and the jet bombers (at that time) were restricted in range, so it was concluded that any immediate redesign of the Fat Man must, of necessity, keep the B-29 in mind as the delivery vehicle.[7]

A Mk 4 planning meeting was held October 4, 1945, at which an optimistic schedule was laid out. The coefficient of expansion of the high-explosive sphere was to be determined by November 1, 1945. The external shape of the bomb and the elements of the firing circuitry were to be settled by December 1, and the sphere assembly and mounting were to be designed by December 15. Drawings of the tail, the cartridge, and the electrical equipment were to be prepared by January 1, 1946. Handling equipment was to be available by February 1; full-scale drops were to be started March 15; a pit and sphere assembly was to be completed by May 15; and the entire bomb was to be ready for stockpile production, with all problems solved, by July 1, 1946. (b)(3)

It is obvious ... that the

estimated date of July 1 for the completed bomb is contingent on the progress made with the pit."[6] However, it was understood that, should the nuclear design be produced, the weapons hardware group was to be ready with the rest of the bomb, and the Z Division swung into high gear.

During design of the wartime Fat Man, there had not been enough time to make a thorough analysis of component functions and their relationships to the overall weapon system. A study was thus started, covering the circuit elements of the bomb and the part played by such factors as simultaneity of switch operation in overall efficiency. Ballistic problems, further described in Chapter III, also were examined. To meet this need, a field-test range was secured, arrangements made for wind-tunnel work, and special telemetry apparatus started into design.

Improvements were made to various elements of the firing system, notably the X-unit, which created the high-voltage surge of current that fired the weapon detonators. The wartime implosion bomb had been equipped with an X-unit whose capacitors were charged to approximately 5600 volts before the bomb was released from the carrying airplane. This not only created a hazard to the bomber crew, but made it necessary to pressurize the X-unit to prevent internal arcing at bomb release altitudes. A safer and simpler X-unit was designed, which was charged after the bomb had fallen to its fuzing altitude, a safe distance from the strike aircraft.

Detonators were modified for easier installation, and much attention was paid to the design of segment molds and the lenses for most efficient implosion of the high-explosive sphere. Extensive tests were made of face pressures between high-explosive segments, and studies were conducted of improved systems of detonator cabling. The protruding Mk III (Yagi) antennas were redesigned to be recessed into the flattened nose of the

The above effort was compounded by the necessity to provide parallel designs for mockup or dummy units. Detonators, for example, were built with inert charges so that they could safely be used in trial sphere assemblies using, of course, dummy high-explosive segments. Various operational units had to be simulated by dummy weights so that these could be attached to assemblies being given shake-table tests.

The Mk 4 work was later delayed by another full-scale test, Operation Sandstone, which was held at Eniwetok in mid-1948. Mr. Henderson headed up the engineering phase of the operation, and Z-Division personnel were assigned to various Sandstone functions. However, as the year 1947 drew to a close, the following accomplishments related to the Mk 4 weapon could be reported to Congress in reply to a request for the status of nuclear ordnance:

1. Selection of an outer case with improved ballistics;
2. Progress on a new fin design;
3. Development of a new antenna system;
4. Development of a cartridge-type assembly to contain bomb fuzing components;
5. Development of new handling equipment;
6. Preliminary studies of a new radar and electromechanical fuze;
7. Establishment of a mechanical test laboratory; and
8. Extensive work in the field of telemetry.[11]

For some time there had been proposals to separate the Z Division from the rest of the Los Alamos Scientific Laboratory. Los Alamos interests were basically that of an experimental nuclear and scientific laboratory, while the Z-Division work was rapidly assuming the aspects of ordnance design and production. This trend brought about the appointment on

In the meantime, at Kirtland Field, members of the Tactical and Technical Liaison Committee, established by the Air Force in connection with the atomic bomb, were also studying this subject. On March 26, 1948, the Committee recommended to Air Force Headquarters that both insertion and extraction of nuclear components be provided, pointing out that such design would increase both aircraft and airport safety. The practicality of this insertion and extraction operation had meanwhile been demonstrated by members of the Z Division working inside a parked B-29 at Kirtland Field.[14] This subject was further discussed in the Sandia Research and Development Board meeting of July 20, 1948, in which it was noted that the problem of extraction was of concern, but that it was necessary to freeze the design to permit production to proceed. Accordingly, action on the problem was temporarily deferred.[15]

Meanwhile, international tensions were increasing. The Communists had seized Czechoslovakia and were being belligerent in Berlin, where the Western powers occupied part of the city as an island in the midst of Soviet-held territory. As a result, the Military Liaison Committee urged that production and stockpiling of the Mk 4 be expedited.[16] The Sandia Research and Development Board discussed assignment of priorities for various atomic programs and, in a meeting May 6, 1948, urged the acceleration of the Mk 4 by every means possible.[17] Working at high speed and under overtime schedules, Sandia released portions of the Mk 4 design as they were completed, and by mid-November 1948 the entire weapon was in production.[18]

It was felt that the Mk 4 could be stockpiled by April 1, 1949.[19] The Preliminary Evaluation Report for the weapon, which provided an engineering examination of the bomb and gaged its success in meeting

specifications, was issued January 15, 1949. A crash program produced test and handling equipment for military training and for possible emergency use.[20] As a result of this intensive effort, the first Mk 4 Bomb entered stockpile March 19, 1949.[21]

Chapter III - The Ballistics Problem

The problem of Mk 4 ballistics received early attention. The Mk III weapon had a diameter of 5 feet to accommodate its large explosive sphere, and a proportionally short length (~~11 feet~~ 10 feet 7 inches) to enable the weapon to fit into the B-29 bomb bay. A 5-foot-square box tail was initially used, and this design was only marginally aerodynamically stable after the tail structure had been internally stiffened and braced. The ballistics group at Los Alamos suggested that the center of gravity be moved as far forward as possible and that the body and tail be streamlined to the utmost. A tail design to provide lift rather than drag as a stabilizing force was advocated, as well as a structural design to minimize vibration and flutter, the location of internal components for best static and dynamic balance, and the elimination of external projections that might cause turbulence or parasitic drag. The report noted that the Mk III had a low ballistic coefficient, that this figure should be increased to improve stability, but that the stubby shape of the bomb would militate against any large increase.

A meeting of Los Alamos and W-47 representatives was held August 25, 1945, to provide an answer to the ballistics problem. Some attendees felt that if the bomb could be lengthened, a relatively high ballistic coefficient might be attained. (b)(1), (b)(3)

This was found to be impractical, due to the large diameter of the Mk 4 and the lack of sufficient clearance under the fuselage of the B-29. As one result of the meeting, it was decided to seek external ballistics advice.[22]

Two days later, Z-Division representatives left for the East Coast to visit the Bureau of Standards, the Aberdeen Ballistics Laboratory, and Langley

Field; and to confer with aerodynamicists and ballistics experts. They were informed that the best tail was a design using four equally spaced airfoils, and that these airfoils had to extend some distance out from the body of the bomb since, at high velocities, the air flow broke away from the bomb contour at approximately the maximum diameter of the bomb. It was felt unwise to permit the velocity of the bomb to exceed Mach 1 (the speed of sound), due to buildup of vibration, and it was suggested that a tail shroud be used to retard the rate of fall of the bomb if this velocity was approached in full-scale drops. The use of a blunt rather than a round nose was recommended in an effort to further retard the rate of fall.

A wind-tunnel test program was outlined, to be conducted at Aberdeen. Body shapes without tails would be initially investigated, and the best shapes fitted with simple fins and tested further. If these designs were not completely stable, a circular tail shroud would be added. These wind-tunnel tests would be made at speeds expected to be encountered in actual drops, and stability of the bomb shapes at higher or supersonic speeds would be checked by firing 20-millimeter-diameter models from a gun. It was felt that little could be done to improve the body of the bomb, due to the dimensional limitations imposed by high-explosive sphere and bomb bay, and that efforts should be concentrated on tail modifications.[22]

It had been decided to start full-scale test drops as soon as possible, and an aerial survey of World War II practice ranges in the vicinity of Albuquerque was made September 19, 1945, by members of Z-1. As a result, Range S-1 (which was renamed the Los Lunas Range) was selected for use. This range was located west of the town of Los Lunas and approximately 25 miles southwest of Albuquerque.[23]

In preparation for the work at Los Lunas, recording and communications gear was installed in trailers which could be based at Albuquerque and

trajectory (and thus a high bomb velocity), and to test bomb operation in a denser atmosphere. The range had been obtained for the Z Division in March 1946, and initially used for Mk III tests. Subsequently, much preparatory work was done at Salton Sea, with Askania stations being established, targets prepared, field communication wire strung along the ground, and radio transmitting and receiving equipment installed.[9]

A half-scale Mk 4 shape was dropped at Salton Sea April 4, 1947. The test demonstrated that the approaching B-29 bombers were hard to see, and this fact, coupled with inaccurate bombing, complicated tracking and camera work. The B-29's developed mechanical trouble as the high-altitude work continued, and electrical problems were created as the wild life around Salton Sea acquired a taste for the insulation of the ground-laid wires. Test operations were temporarily halted while new B-29's were secured, wiring strung on poles, and a new target array installed.[25]

By the fall of 1947, it was felt that if the roll of the bomb in flight could be controlled, many erratic ballistic actions could be eliminated. One way of controlling roll was to provide a tail that would spin freely, and this was tried. It involved difficult manufacturing problems and was therefore not thoroughly pursued. Another proposal was to use the shroud that had been initially proposed as a means of providing drag. This shroud would add considerable weight to the tail, thus adversely shifting the center of gravity aft, and designs were tested for a lightweight tail cone to counter this added weight.[26]

By early March 1948, drop tests were indicating improved ballistic characteristics. Releases to supply performance data on fin shape indicated that a large-plan fin (with an area increased approximately 25 percent above the plan area of the standard fin) would produce

less yaw in flight than the standard fin. Fairly consistent performance was also obtained using a thin fin (with a plan area decreased approximately 25 percent) and a circular shroud. Neither of these two types, however, gave completely satisfactory ballistic performance.[27]

Members of the Armed Forces Special Weapons Project suggested that a group of aerodynamicists might be able to suggest improvements in ballistic characteristics, inasmuch as a great deal had recently been learned concerning actions of bodies passing through the transonic region, which had been pierced by manned aircraft only a few months previously. Consequently, representatives of Northrop, Rand, Douglas, North American, Boeing, Wright-Patterson Air Force Base, Inyokern, and Aberdeen formed an advisory panel which initially met May 26 and 27, 1948. The panel suggested that thin fins with flat sides and wedge cross sections would perform better than fins with curved sides and airfoil cross sections. It was also proposed that the planform of the fin be enlarged and drag introduced by the use of plates or spoilers to hold the velocity of the bomb below the transonic range. Arrangements were made to use the Cooperative Wind Tunnel at the California Institute of Technology, which had a greater velocity range than the Aberdeen tunnel.[28]

The flat-sided wedge fins were subsequently tested at the Cooperative Wind Tunnel and exhibited good stability.[22] Consistently good results were obtained from drop tests and, in mid-September 1948, the large-plan wedge fin was tentatively selected for use.[29,30] Detailed results of tests at the Cooperative Wind Tunnel became available October 1, 1948, and confirmed the results noted above. Perforated tail plates were tested on two bombs; one with a square plate and the other circular. The first gave improved control over pitch and yaw, while the second resulted in decreased control--hardly a conclusive test.

Since there was now a limited amount of time and drop tests that could be made, it was decided to concentrate on trials of a large-plan wedge, a thin-fin shroud wedge, a dorsal wedge, and a large plan with a sloping leading edge. All these, it was felt, would have about the same ballistic characteristics. A closer examination of wind-tunnel data subsequently narrowed the choice to a large-plan wedge or a thin-fin shroud wedge. It was then found that the reliability of the thin-fin shroud declined in high-speed, high-altitude drops, whereas the large-plan wedge did not, and the latter design became the obvious choice.

Aberdeen wartime experience with certain experimental bombs had indicated that a "flap" placed at the rear of a bomb shroud (which presented a greater angle of attack to the approaching air than the fin) would help to stabilize bomb flight, and large-plan wedge and thin-fin shroud tails were prepared with this modification. The first to be dropped was the large-plan wedge. One drop showed such excellent flight characteristics--with pitch and yaw of only about 2-1/2 degrees and a ballistic velocity coefficient only slightly lower than that of the thin-fin shroud--that it was deemed advisable to concentrate on further drops of this type, rather than expending time and energy on the thin-fin shroud, which was difficult to fabricate.[22] Accordingly, the large-plan wedge design was frozen for Road production in December 1948.

(b)(1), (b)(3)

Chapter IV - Mk 4 Bomb Description

Since the Mk III Bomb was the immediate predecessor of the Mk 4, a brief review of its major design features is of interest. (b)(3)

The Mod 1 retained the Type A pit, but incorporated an improved fuzing and firing system including the Mk III Mod 2 X-unit (an inductance type), ER-12-10 batteries, and 1E20 detonators. (b)(3)

The original Mk 4 Mod 0 Bomb was similar in many respects to the Mk III Mod 2 (see Figure 2). (b)(3)

The Mk 4 was a free-fall, air-burst, implosion-type bomb 60 inches in diameter and 128 inches long, and weighing 10,900 pounds.[37] (b)(1), (b)(3)

These yields compared to the wartime "Little Boy" and "Fat Man" bombs of 18 and 23 kilotons, respectively.[40] (b)(3)

The external ballistic case was made of mild steel, 3/8 inch thick, and was built in three sections for ease of assembly.[37] The front and rear sections bolted directly onto the fore and aft flanges of the sphere

case. The center "belly band" section was split at the top so that it could be spread apart with assembly tools and slipped over the sphere flanges for positioning over the center section of the sphere. Tension bolts pulled the split-band together at the top. A large rubber gasket sealed the surfaces where the steel case met the aluminum sphere case. The forward case supported the antenna nose plate, which could be removed for access to the sphere. The inflight insertion gear was supported by the forward case. The four fins, which were of aluminum sheet-metal construction, were bolted to the rear case.

(b)(3)

The cartridge structure supported the fuzing components, was cylindrical in shape, and used riveted aluminum sheet-metal construction. The X-unit was bolted to the forward end of this assembly, and the entire unit was

(b)(1), (b)(3)

The following aircraft were equipped to deliver the Mk 4. For the Air Force; B-29, B-36D, B-36F, B-47B, B-50A, and B-50D. For the Navy; AJ1 and AJ2. Since the Mk 4 was originally designed for carriage by B-29 and similar land-based aircraft, no provision had been made for resisting catapult loads. With the development of Navy aircraft capable of taking off with the bomb from the deck of an aircraft carrier, some difficulty at the sway-brace locations was encountered. This was overcome by redesigning the sway braces in the aircraft bomb bay so as to distribute the load over a sufficient area to prevent damage to the outer case of the Mk 4.

The Mk 4 Mod 0 Bomb entered stockpile March 1949. It was not equipped for inflight nuclear insertion. It included the Type C pit and had an inflatable rubber gasket to seal the ballistic case. Baro ports were located at the nose of the bomb, and the entire interior of the bomb case was used as a "plenum chamber" to provide static pressure to the baroswitches.

The "Mod-Alt" change system was not in use at this time, and major changes were processed under a "block" change system. All weapons in a given "block" of units incorporated the same changes. In May 1950 the Mk-Mod-Alt weapon designation system was instituted, and the weapon was divided into three major assemblies, bomb, fuze, and capsule.[42] The bomb capable of inflight nuclear insertion became the Mk 4 Mod 1

(previously identified as the Block 7 weapon). It also included a solid rubber gasket for sealing the ballistic case. Since it had a Type C pit, the complete bomb nomenclature was Mk 4 Mod 1-C.

The Mk 4 Mod 2-C Bomb incorporated a baro manifold, which was a circular copper tubing assembly installed in the rear ballistic case.[43] Static pressure was provided from intake ports in the rear cover plate through flexible hose leading to the manifold and additional flexible hose connected the manifold to the baroswitches. The accuracy of the baro system was improved by this change, since it no longer depended on a sealed ballistic case for a static pressure source.

The Mk 4 Mod 2-D Bomb incorporated a Type D pit with a higher yield.[44] Special handling equipment was required for insertion of this capsule into the pit, and included a loading tool and a capsule alignment tool or loading trough. By the end of 1951, all Mk 4's had been retrofitted to the Type D pit.[45]

The Mk 4 Mod 3 Bomb incorporated a lightweight magnesium antenna nose plate for easy manual handling. This permitted simplification of the inflight nuclear insertion gear and speeded the operation. Since this change was incorporated on bombs having either the Type C or D pit, it was identified as the Mod 3-C or Mod 3-D.

The "cartridge" became, under the new system, the Mk 4 Mod 1 Fuze. This included the AR-10A "Archie" radars (four required), BS-4 or BS-5 Baroswitches (six required), M-127 "clock" timers (eight required), Mk 4 X-unit, and lead-acid ER-12-10 batteries. The components were mounted on an aluminum structure for convenient installation (b)(3)

interval before supplying power to the firing set. This time interval allowed the airplane to get beyond radar fuzing range, preventing premature detonation by radars ranging off the aircraft. Closing of the arming switches by the clocks allowed current from the 30-volt battery packs to flow through the X-unit choke and the closed firing switch. This current flow caused a magnetic field to be built up in the choke.

At a predetermined altitude, well above the desired burst height, baroswitches closed, allowing the radars to start transmitting and receiving. At the preset burst height, the ranging of any two of the four radars off the target operated a relay network which opened the firing switch in the X-unit. The rapid opening of this firing switch caused a collapse of the magnetic field in the choke, transferring electrical energy to a condenser. When the voltage in the condenser built up to approximately 4000 volts, the spark-gap switch spontaneously broke down, allowing current to flow through the gap and the detonator circuits.

Bridge wires in the detonators were vaporized by the high-voltage pulse. This detonated the explosive material in the detonators, which in turn ignited the high-explosive charges of the sphere, creating a spherically convergent detonation wave which compressed the nuclear components to supercriticality.

(b)(1), (b)(3)

Chapter V - Mk 4 Improvement

After the Mk 4 entered stockpile, design improvements continued despite the fact that much of the engineering staff was transferred to work on other weapons. A list of desirable modifications was compiled, based on a joint military-Sandia survey, and, after thorough review, was formally issued May 18, 1949, under the title "Desired Military and Technical Characteristics of FM Type Atomic Weapons."[48]

Five areas were listed, including weapon battery, ballistics, inflight nuclear insertion and extraction, lightweight case, and improved fuzing system. Battery improvement, due to the state of the art, was deferred for later consideration; the ballistics story has been developed in Chapter III.

The inflight nuclear insertion and extraction project was already well under way, as studies had started in early 1948, (b)(3)

Facilities for supporting the antenna nose plate and sphere access door while the nuclear capsule was being guided into position were also provided. This support device was temporarily bolted to the nose of the bomb while it was in the bomb bay of the aircraft proceeding to target, and was manually operated.[18] A later production version eliminated the support arms for the nose plate and access door, which by that time had been much reduced in weight.

(b)(3)

It was originally felt that the Mk 4 should be protected against flak by an outer case of 1/4-inch-thick armor plate. Those attending the August 25, 1945, meeting that discussed general bomb features had felt that this protection was unnecessary,[22] and as a result the weapon was constructed with a case of 3/8 inch-thick mild steel. The Bureau of Ordnance later noted that aluminum offered somewhat better protection than steel, when equal weights of materials were used, and as a result some reduced-scale aluminum cases of 3/4-inch thickness were designed, built, and drop tested in 1947. However, the fact that strong steel cases were normally used in bomb construction led the Mk 4 designers back to this material.

The Air Force was of course vitally interested in anything that would reduce the weight of the bombs they carried, in order to increase the range and altitude of the carrying aircraft, and this subject was discussed in various meetings at Kirtland Field and the Los Alamos Scientific Laboratory during the fall of 1948.[51] Sandia Laboratory forwarded a memorandum to the Division of Military Application on September 29, 1948, stating that it should be possible to reduce the weight of the Mk 4 by using aircraft-type design in the front and rear case sections, but that this work would delay the Mk 4 stockpile delivery date.[52] It was suggested that some preliminary design be undertaken by aircraft engineers cleared as members of the aerodynamics panel.

This topic was mentioned in the September 30, 1948, meeting of the Sandia Research and Development Board, with Sandia pointing out that the change would necessitate a major change in material sources, tooling, and bomb handling equipment, and that a thorough stress analysis would be required.

Subsequently, considerable correspondence on the subject developed between the Division of Military Application, Military Liaison Committee, AEC, and Sandia, with efforts being made to determine whether or not there was a real need for the heavy case for either flak protection or storage.[53,54,55,56] On December 24, 1948, Sandia informed AEC that a development program for reduction of Mk 4 Bomb weight had been established at Project Roger (the Army's Rock Island Arsenal, which was handling certain weapons production work) and its subcontractor, the American Car and Foundry Company. The purpose of this program was to evaluate and recommend weight reductions based on an aluminum outer case produced by the same tools used for forming the steel casing.[57]

Meanwhile, various pressures were exerted both for and against the design of a lightweight case,[58,59,60] with the matter being decided February 17, 1949, when the Division of Military Application directed Sandia to subcontract the design of an aluminum case.[61] On March 16, Northrop Aircraft, Inc., was invited to design a riveted case,[62] and in May the American Car and Foundry Company was asked to design a welded case.

Ballistic testing of both the riveted and welded cases was conducted in December 1949, and static and dynamic tests were run at Wright Field.[63] These proved that both cases were satisfactory, and, inasmuch as cost and weight comparisons were roughly equivalent, it was decided to procure both types.[64,65,66,67] Production of the riveted design was turned over to Project Royal (the AEC manufacturing facility at Kansas City), and the

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American Car and Foundry Company started to fabricate the welded case. A memorandum from Sandia to the AEC April 5, 1950, noted the desirability of minimum weights for all bomb components, and stated that Sandia was investigating the possibility of also reducing the weight of the inner sphere case.[68] However, about this time, the entire weight-reduction program was transferred from the Mk 4 to the Mk 6 design.

(b)(1), (b)(3)

Design and production problems were encountered with the Abee and, for a time in late 1949 and early 1950, consideration was given to a simple barometric fuze. However, the Los Alamos requirement that the bomb detonate at a relatively precise distance above the target inevitably brought the designers back to consideration of a radar fuze.

Meanwhile, some short-range improvements were made to the Archie.[69] Various range (height of burst) modifications had been provided by the use of separate delay lines that were soldered into the instrument for each range. This made it difficult to alter the height of burst rapidly when targets were changed,[70] and in the fall of 1949, a modified Archie (AR-10A) with plug-in delay lines was introduced, eliminating the soldering task. A still more powerful radar (to be called Albert) was proposed, and work proceeded intermittently on this design.

At a meeting of the Sandia Research and Development Board, on September 19, 1949, an addition of a "Black Box" to the radar system was considered.

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(D). Comparative Description of Bombs

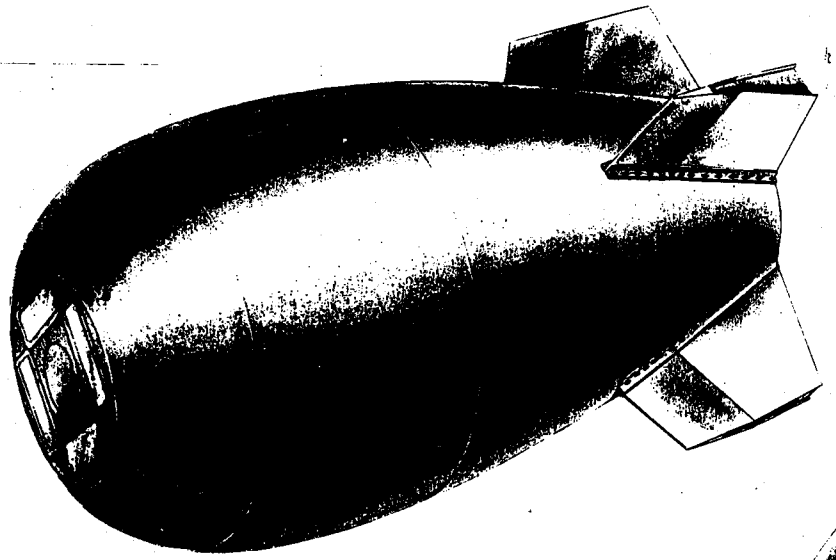
Figure 1 shows the Mk IV and Mk III FM bombs assembled. It will be noted that in external appearance the Mk IV is much cleaner in design. The ellipsoid and tail fittings, the antennas, and the bomb lug have been eliminated as protuberances. The lug is recessed, and the antennas are flush-mounted in the noseplate. The complex box tail of the Mk III has been replaced by four airfoil-type fins.

Figures 2 through 6 illustrate the weapons and their components, and Figure 7 compares the breakdown of major components of the two weapons. The difference that is most readily apparent is the placement and mounting of the electronic fuzing and firing equipment into one easily removable cartridge rather than on cones placed on opposite sides of the sphere. A study of these pictures will identify the corresponding components of the two weapons.

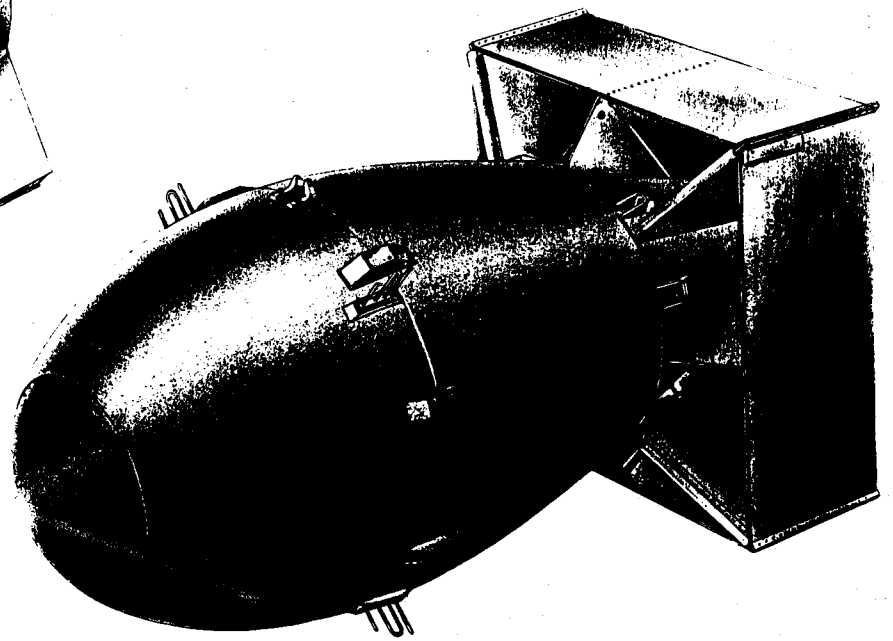
Figure 8 illustrates and compares the field assembly breakdown of the weapons. In this figure the split-band is removed from the Mk IV for installation of the detonators. The comparison clearly illustrates the greater simplicity in field assembly of the Mk IV.

Figure 9 illustrates and compares the field assembly breakdown of the weapons when the detonators are installed in the Mk IV at the rear base. It can be seen that further simplification is achieved if the detonators are installed before the bomb goes forward.

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MK IV MOD 0 FM



MK III MOD 0 FM

Fig. 1. -- Mk IV and Mk III FM Bombs Assembled

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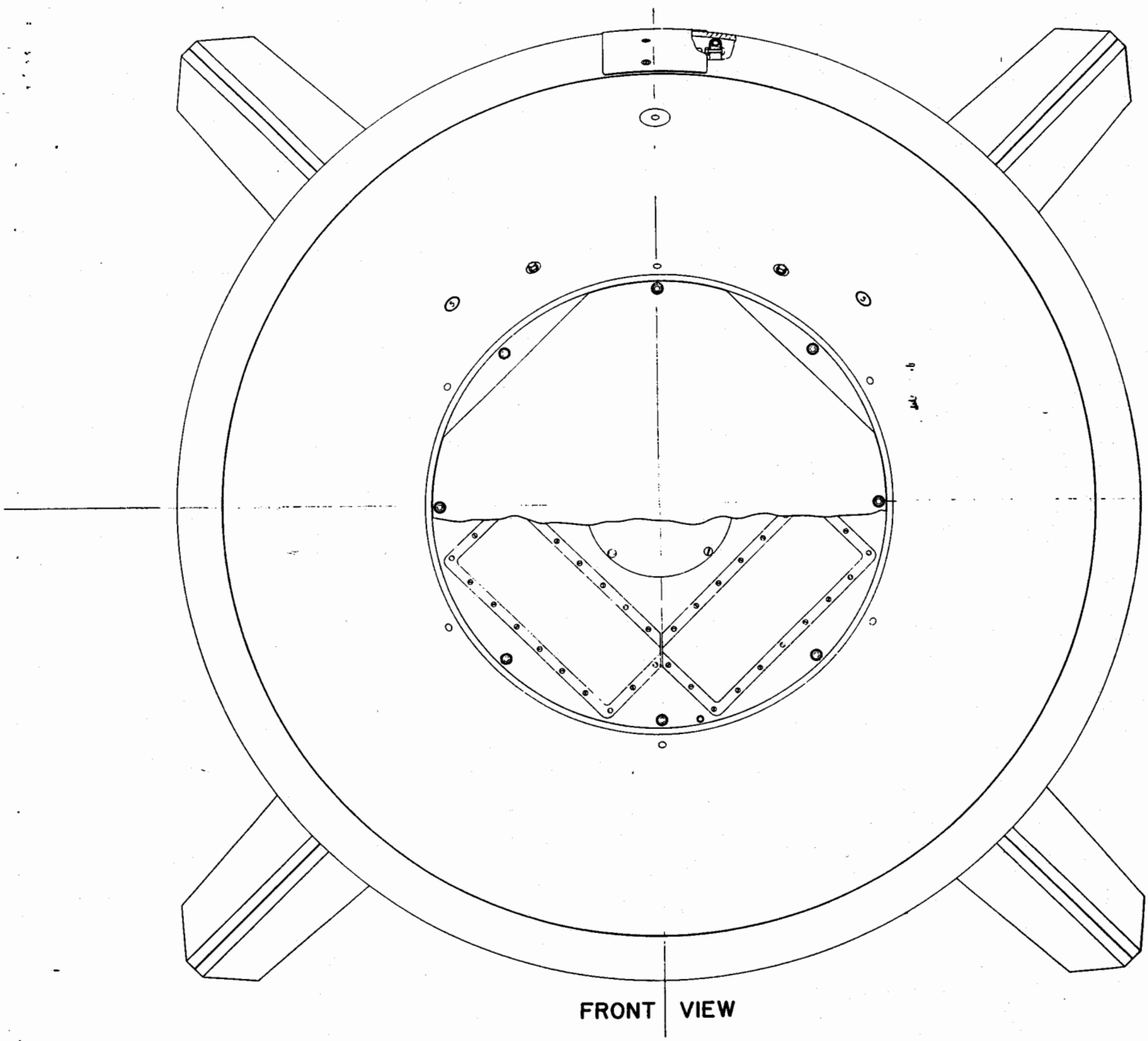
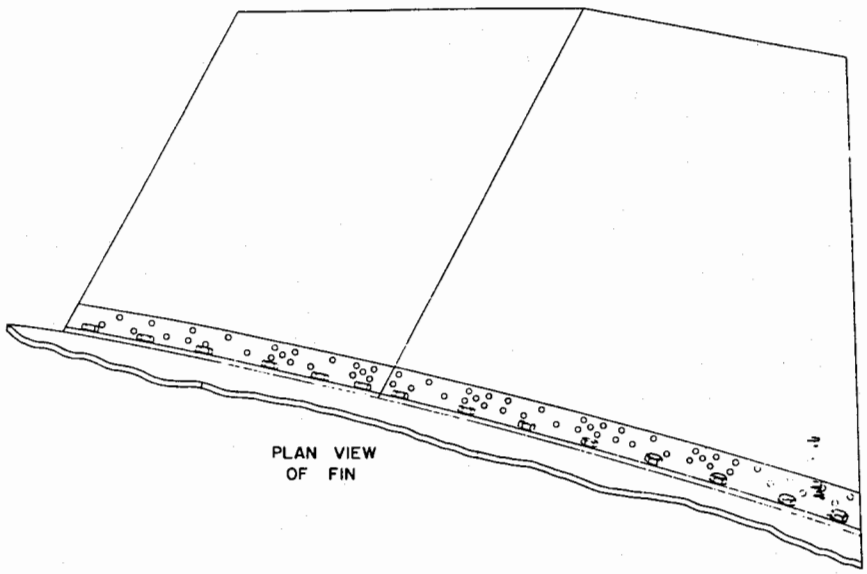
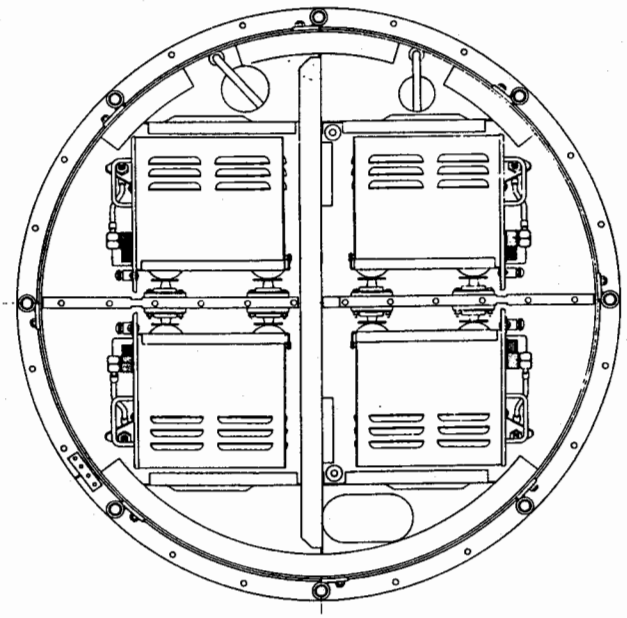


Fig. 3. -- Front View of Mk IV Bomb



PLAN VIEW
OF FIN



REAR VIEW OF CARTRIDGE
WITH END PLATE REMOVED

Fig. 4. -- Plan View of Fin and Rear View of Cartridge

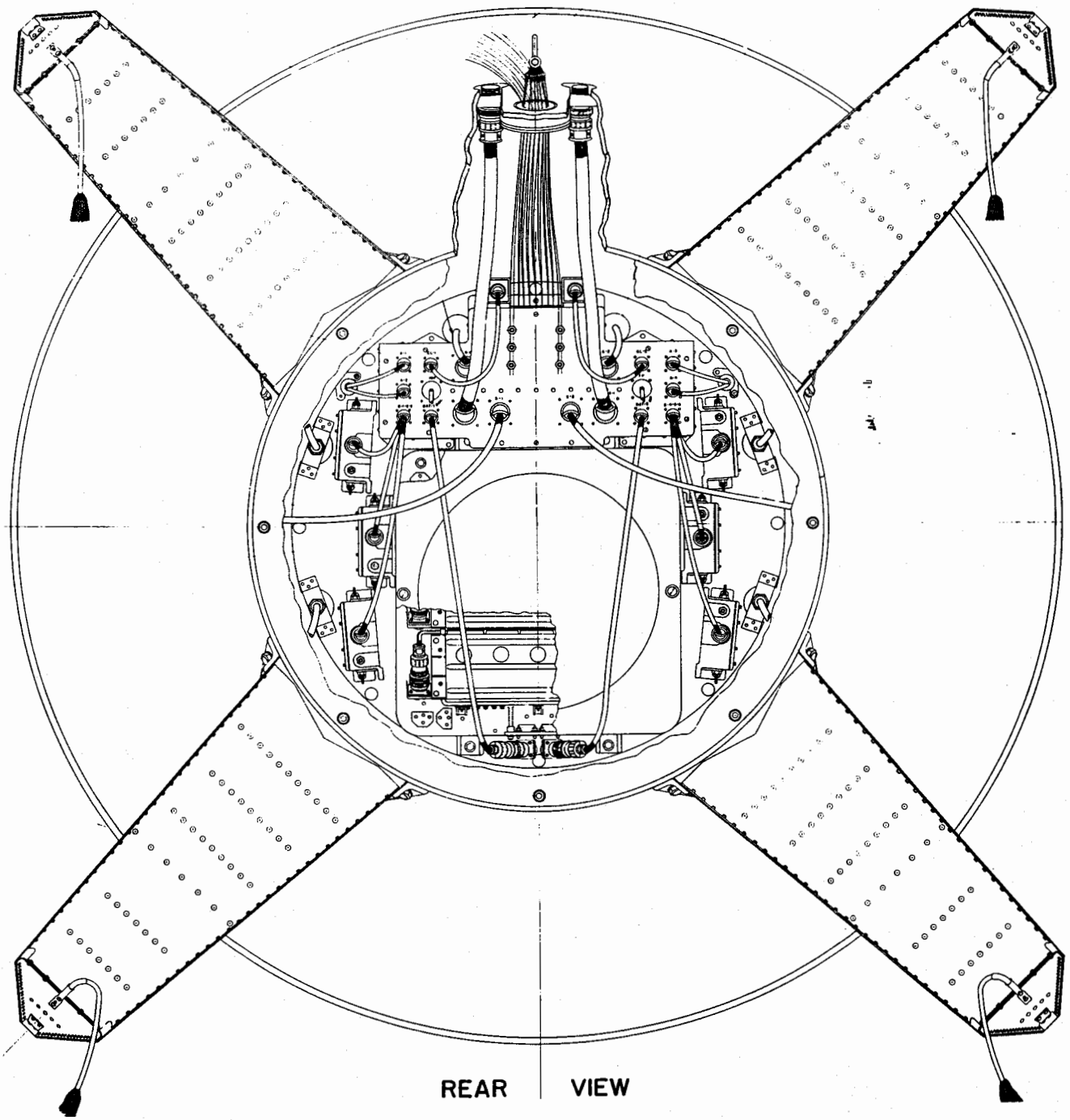


Fig. 5. -- Rear View of Mk IV Bomb

(II). MK IV MOD 0 FM BOMB

(A). Over-All Design of Bomb

(B). Outer Case

(C). Sphere (High-Explosive Container)

(D). Ballistic Design

(E). Electronic Cartridge

(F). Electrical Fuzing and Firing System

(G). Detonators

(H). High-Explosive Charge Assembly

(I). Systems Reliability Analysis

(J). Nuclear Components

(II). MK IV MOD 0 FM BOMB

(A). OVER-ALL DESIGN OF BOMB

(1). Functional Use and Design Requirements

The Mk IV Mod 0 FM is an implosion-type atomic bomb based upon the same fundamental principles of nuclear fission as those of the Mk III FM. It incorporates an improved fuzing and firing circuitry over that in the Mk III Mod 0 weapon and the same basic circuitry as that in the Mk III Mod I weapon. The bomb was re-engineered to provide for greater ruggedness, greater dependability, easier field techniques, and better ballistic performance than either of the Mk III versions.

In addition to the detailed discussion of these various factors presented in later sections of this chapter, the following general requirements, which apply to the entire bomb, are discussed in this section.

(a). The bomb must withstand expected flight and handling loads.

(b). The bomb must withstand atmospheric conditions as required for storage and operation.

(c). The external dimensions of the bomb must be kept within the box dimensions of the Mk III FM and must be such that the bomb will fit into a B-29 bomb bay.

(2). Discussion, Tests, and Calculations

(a). Flight Handling Loads. -- Calculations and tests indicate that the bomb will withstand the following load factors shown in the memorandum "Minutes of Meeting to Establish Load Factors for '41'," (Ref SLE-3-1477): 1,2

Airplane Flight Loads (S.F. = 1.5)

	Limit	Ultimate
Vertical	4.67 down	7.0 down
	2.0 up	3.0 up
Longitudinal	4.0 aft	6.0 aft
	5.33 fwd	8.0 fwd
Lateral	2.0	3.0

Free Flight Loads

A resultant static fin load equal to the weight of the bomb and located 1/3 of the fin height from the base of the fin.

Ground Handling

	Limit	Ultimate
Vertical	+4	+6
	-2	-3 (based on trailer weight)
Longitudinal	6	9
Lateral	2	3

The bomb is designed to withstand normal handling load factors while being assembled or while being transported by any practicable surface or air means. An empirical standard of vibration testing of 10 to 55 cps constant amplitude at 10 g maximum acceleration for 45 minutes in each of three

mutually perpendicular planes has been adopted for certain components. Although complete knowledge of transport vibration is not available at this time, some data have been received.

Additional information is being obtained and a study is in progress to determine the application of this information to design.[3,4] Present calculations and experience show that the bomb has adequate factors of safety to withstand all but the most exceptional transport loads. Vibrations recorded during drop tests indicate that all components have adequate factors of safety for free flight conditions.[5] Actual drop tests with HE have not been made.

There has been considerable experience in the use of assembled test bombs without any failures caused by normal handling.

A Mk IV Mod 0 FM unit loaded with dummy charges and electrically functional was subjected to abnormal handling when the trailer on which the unit was being towed broke down. An electrical check and inspection of the unit was made after the accident. Aside from fin damage and minor scratches on the outside of the case, no failures were found.[6]

(b). Environmental Limitations. -- The original engineering concepts of atomic bombs required that each unit be handled under specific, carefully controlled conditions in both storage and use. The growth of storage and tactical philosophies has created the desire to provide for the storage and use of atomic weapons under highly adverse atmospheric conditions. The Mk IV FM partly fulfills this long-range development ideal. A chart showing the recommended limiting environment for components is shown on pages 27-29.

(1). Long-Term Storage (Nonoperational). -- It is estimated that the components of the unit in long-term dead storage can withstand temperatures ranging from -40°F to 149°F with the exception of the HE assembly (long-term high temperature of 95°F to 100°F maximum, and slow rate of temperature change). For long-term storage most of the components should not be exposed to relative humidities greater than 40 per cent; all components are therefore packaged to provide protection against moisture. All components except the nuclear material, batteries, detonators, and

cartridge are stored in the bomb case. The assembled bomb case, which is stored in a crate, breathes through one desiccator port. A desiccant is placed inside the case for protection against moisture. All other components are packaged under Method II A (dry-air technique). By this method the item is packaged in a moisture-proof barrier along with a sufficient amount of desiccant.

(2). Exposure During Assembly. -- The relative humidity in the assembly area should not be greater than 50 per cent at 80°F.

(3). Exposure of Completely Assembled Bomb. -- It is estimated that the assembled bomb can be exposed to temperatures as low as -40°F for at least as long as the life of the desiccators (approximately two weeks) provided the battery temperature is increased to above 0°F before use. It is also estimated that the bomb, less its nuclear components, can be exposed to 120°F for two weeks. With nuclear components, the bomb can be exposed to temperatures up to 120°F for three days and up to 105°F for two weeks.

Leakage tests indicate that the outer case sealing will protect the assembled bomb from exposure to relative humidities up to 100 per cent for moderately long periods providing the desiccators are replaced when necessary (every two weeks).

(4). Operational - General. -- Drop tests of the Mk IV Mod 0 FM as well as laboratory component tests have indicated that the bomb will operate satisfactorily at temperatures ranging from -40°F (with heaters functioning in the clock bank and battery box) to 120°F, at pressures ranging from atmospheric to 7 psi, and at relative humidities of 80 to 90 per cent.

The temperatures of the internal components at detonation is not definitely known; it is expected, however, because of the short time of fall, that the temperatures will be very close to those at the time of release. Tests indicate that the temperature inside the bomb bay with a Mk III Mod 0 bomb in it will stabilize at about 25°F to 28°F above free air temperature (Ref SMD-575, Preliminary Investigation of B-29 Bomb Bay Temperatures). Tests on a Mk III Mod 0 bomb indicate that it takes at least four hours for the temperature of the internal components to reach -40°F when the temperature of the air to which the bomb is exposed is rapidly changed from 70°F to -65°F (Ref SMD-435, Low Temperature Tests of a Nagasaki-type Bomb). These tests also indicate that it takes at least eight hours for the temperatures of the internal components to change from 70°F to -65°F when the air temperature is -65°F. On the basis of the results of these tests, it is believed that the temperature of internal components will not be below -40°F when free air temperature at altitude is -65°F or above.

(c). Dimensional Limitations. -- The over-all dimensions on the bomb were limited to the box dimensions (60 x 60 x 128 inches) of the Mk III FM, and were to be such that the bomb would fit in a B-29 bomb bay. Tolerances on drawings allow the external diameter of the bomb to exceed 60 inches by 0.16 inch. The bomb fits into the bomb bays of the B-29, B-50, AJ-1, and B-36 airplanes. The distances between the fin guide rails in the B-29 bomb bay dictated, for clearance purposes, a 59-inch box dimension for the fins.

The total weight of the bomb is 10,900 ±240 pounds, and the cg is 43-7/16 ± 1/4 inches from the nose; the transverse moment of inertia is approximately 9,400,000 in.^{2} lbs and the polar moment of inertia is approximately 4,400,00 in.^{2} lbs. Component weights of one unit are tabulated on page 30.

(d). Other Limitations. -- The unit, less its nuclear material, after being tested and assembled, can be dispersed for a period of two weeks without rechecking. Two weeks is the estimated life of the desiccators. The batteries will maintain proper charge for a period of three weeks.

There are four airplanes which can accommodate the bomb at present, the B-29, B-50, AJ-1, and B-36. Satisfactory ballistic drop-tests have also been made from the B-47, but as yet it is not wired for making the electrical checks required in flight.

The best predictable results can be obtained in all drops that are made from an altitude of 32,000 feet at normal B-29 release velocity (310 mph true air speed). However, satisfactory drops can be made at altitudes up to at least 40,000 feet and at release velocities up to 0.8 Mach number.

Drop data indicate a trend in the increase of baro-switch pressure of approximately 440 feet altitude per 100-mph true air speed increase in release velocity. For normal B-29 drops this effect is so small as to make it impracticable to correct the baro-switch setting. However, if release velocities vary over a wide range, corrections should be made.

No definite effect of variation in release altitude from 32,000 to 40,000 feet has been noted from tests conducted to date. There is an indication that lower release altitudes may cause baro switches to close at higher than normal altitudes. Insufficient data exist at this time to establish definitely the effect of variation in release altitudes upon baro-switch closure. Baro-switch closure can, however, be most closely predicated at drops from 32,000 feet. Consideration should therefore be given to making drops at or near this altitude whenever radar jamming is expected.

Weather limitations during drops are not accurately known; however, it might be expected that all-weather use of this weapon can be made only at the possible expense of performance.

Atmospheric turbulence, with rare exceptions, will affect the ballistic accuracy of the bomb by only 100 to 200 feet. If unpredicted ballistic winds, such as might be encountered in a cumulus cloud, reach 100 mph or more, the impact point may vary as much as 1000 feet.

Present indications are that a fairly large reduction in blast efficiency may result from detonation in rain or fog. The probability of the Archies' ranging on clouds is very low.

The effects of icing during a drop are not definitely known. The ballistic performance, antenna operation, and baro-switch operation may be affected to a certain degree by accretion of ice upon the unit. However, on the basis of existing limited knowledge, it is believed that the probability of detrimental effect of icing is low unless severe icing conditions are encountered.

(e). Dependence upon Personnel Performance. -- The simplicity of the design of the Mk IV Mod 0 FM and the reduction of necessary assembling and testing in the field greatly lessen the probability of human error; therefore the quality of personnel in the field need not be as good as that required for the Mk III without sacrificing reliability. However, because of the importance of proper functioning of this weapon, all operations should be performed by thoroughly trained personnel.

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Chart of Recommended Limiting Environment for Mk IV Mod 0 Components
(Values based upon calculations, tests, and/or estimates)

Item	Mechanical Strength	Temperature				Relative Humidity		Pressure		Vibration
		Short Term		Operational		Short	Opera-			
		High	Low	High	Low	Term	tional	High	Low	
(A). Outer Case										
(1). Rear Case (Attaching Bolts)	12,000 lbs on each of two fins; MS = 0.28									
(2). Split Band (Welded Bolt Lugs -- based on yield strength of bolts)	MS = 0.06									
(3). Forward Case (Attaching Bolts)	MS = 5.25 for 5-g load factor									
(4). Antenna Noseplate		+150°F	-67°F	+150°F	-67°F			10 psi differential		10-55 cps; 10 g max; 90 min in each of 3 planes
(5). Fin										
Calc Total Load	MS = 0.45 for 12,000-lb load, 16,700 lbs at failure									
Test Total Load										
(B). Sphere										
(1). Bursting Strength	MS = 34.4 at 41 psi									
(2). Segment Bolts	MS = 5.1 at 41 psi									
(3). Trunnion Attachment	MS = 7.7 for 3-g load factor									
(4). Lug Attachment	MS > 0.033 for 7-g load factor									
(5). Lug	MS = 0.31 for 7-g load factor (neutralized by local plastic bearing failure until actual stress equals allowable)									
(C). Electronic Cartridge		+149°F	-40°F	+149°F	-40°F	50%	80-90%		3 psi or lower	10-55 cps; 10 g max; 30 min in each of 3 planes (cartridge body)
(1). Calc Cantilever Strength	MS = 13.0 for 10-g vibratory load factor									
(2). Cartridge Attachment	MS = 3.1 for 10-g vibratory load factor									
(3). Junction Box Attachment	MS = 5.2 for 10-g vibratory load factor									
(4). Battery Box Attachment	MS = 21.0 for 10-g vibratory load factor									
(D). X-Unit		+149°F	-65°F	+149°F	-22°F Spec -40°F Test	50%	80-90%		7 psi Spec 3 psi Test	10-55 cps; 10 g max; 45 min in each of 3 planes

$$\text{Margin of Safety, MS, } = \frac{\text{allowable load}}{\text{applied load}} - 1$$

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Chart of Recommended Limiting Environment for Mk IV Mod 0 Components (Cont)
(Values based upon calculations, tests, and/or estimates)

Item	Mechanical Strength	Temperature				Relative Humidity		Pressure		Vibration
		Short Term		Operational		Short Term	Operational			
		High	Low	High	Low			High	Low	
(E). Junction Box		+149°F	-40°F or below	+149°F	-40°F or below	50%	80-90%		3 psi or lower	10-55 cps; 10 g max; 45 min in each of 3 planes
(F). Archie		Estimated +149°F or above	-40°F	Estimated +149°F or above	-40°F	50%	Estimated 80-90%		3 psi or lower	Mounted for vibration isolation
(G). Battery Box with filled Batteries		+120°F (2-week test)	-4°F (3-day test) -40°F or lower if battery temp is stabilized above -4°F before use	+149°F	-4°F -40°F or lower with heaters	50%	90-100%		3 psi or lower	10-55 cps; 7 g max; 45 min in any of 3 planes
(H). Baro Switch		+120°F or above	-65°F	(Variation from -65°F to +120°F causes max error of 1520 ft below to 590 ft above set altitude)		50%	80-90%	Below -1430 ft alt	Above 30,000 ft alt	10-55 cps; 10 g max without failure. Vibration caused appreciable chatter.
(I). Desiccator		+350°F	-65°F	+350°F	-65°F	100%	100%			10-55 cps; 10 g max; 15 min in each of 3 planes
(J). Detonator						50%	80-90%			

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Chart of Recommended Limiting Environment for Mk IV Mod 0 Components (Cont)
(Values based upon calculations, tests, and/or estimates)

Item	Mechanical Strength	Temperature				Relative Humidity		Pressure		Vibration
		Short Term		Operational		Short Term	Operational			
		High	Low	High	Low			High	Low	
(K). HE										
(1). Without Nuclear Material		±155°F for short periods; ±120°F for moderately long periods. +95 to +100°F for long-term storage.	No definite limit; slow rate of temperature change.							
(2). With Nuclear Material		±120°F for short period; ±105°F for 2 weeks.	No definite limit; slow rate of temp change.	±120°F	No definite limit.					
(L). Nuclear Components [1]	210-lb load in bending, compression, and tension									100,000 stress reversals; 10 to 60 cps; amplitude of 0.016 in.

[1] Long Term: Exact information on long-term storage can only be obtained over a long time. It is estimated that all components except HE can withstand temperatures ranging from ±149°F to -40°F. The upper temperature limit of HE is 95°F to 100°F. All components are packaged for protection against moisture.

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Component Weight Breakdown of Mk IV Mod 0 FM

Item	Weight (lbs)
Completely Assembled Unit	10,866

(B). OUTER CASE

(1). Functional Use and Design Requirements

The outer case of the bomb serves to provide

(a). An adequate structural member on which the tail fins and antennas can be mounted;

(b). A housing for protecting the internal components against damage from handling, weather, and low-velocity fragment damage; and

(c). A suitable ballistic contour.

In addition to performing those functions, the case has the following design requirements to meet:

(a). Accessibility must be provided to the detonators on the sphere with a minimum of disassembly in the field.

(b). Easy removal of the electronic cartridge containing the fuzing and firing equipment must be provided.

(c). Accessibility must be provided for insertion or extraction of the nuclear material by handling a minimum number of relatively small and lightweight components.

(d). The vibration transmitted from the case to the internal electrical components must be kept to a minimum.

(e). All case openings must be sealed with internal gaskets.

(2). Discussion, Tests, and Calculations

To provide sufficient strength for mounting the tail fins and the antennas as well as for supplying the necessary handling, weather, and fragment protection for the components, the major portion of the outer case is made of 3/8-inch mild steel. Since the front and rear of the bomb are protected by the strike aircraft structure, they do not require as much fragment protection; hence the tail cone of the rear case is 1/4-inch mild steel; the antenna noseplate is cast aluminum alloy; and the rear cover plate is 1/2-inch aluminum alloy.

Strength tests and calculations[1,2] indicate that the mechanical strength of the outer case is adequate (Ref SMD-489, Stress Test on 1/4-inch and 1/8-inch Mk IV Cone). No case damage during the normal handling and flight of 106 units has been noted. (43 of these were the later models with 1/4-inch tail cones.) One bomb with dummy internal weights was accidentally dropped from a B-29 bomb bay onto a concrete runway. The only resulting damage to the case was flattening of the split band and failure of the bolts attaching the rear case to the dummy weights. After the dent was removed from the split band, all components of the case were reusable.

A suitable ballistic contour has been achieved for the bomb as discussed under Section D, page 40 . A clean outer contour is maintained by using cavity-type antennas in the nose, a recessed lug, and flush-mounted safing plugs and pull-out plugs.

Case vibrations induced by the fins must be transmitted through the damping mass of the sphere before reaching the cartridge, which is cantilevered from the rear of the sphere. Tests which have been conducted indicate that the magnitude of vibration to which any electrical component of the cartridge will be subjected is probably less than one half that in the outer case at the base of the fins.[5]

Gasket-type sealing is provided for all openings in the outer case; thus the case serves as a container for the protection of internal components against moisture. Experience gained from long-term storage will determine whether the sealing is sufficient to allow long-term, high-humidity storage without the use of an external sealed container. Leakage tests that have been conducted to date indicate that adequate sealing exists for all operational purposes. However, inasmuch as considerable difficulty was experienced in initial procurement and quality control of inflated-type split-band gaskets, work is in progress to improve this gasket.

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(3). Comparison with Mk III Mod 0 and Mod 1 FM

Item	Mk IV	Mk III
Case structure	Split band, forward case, and part of rear case of 3/8-in. mild steel. Antenna noseplate of cast aluminum alloy. Rear cone of rear case of 1/4-in. mild steel, rear cover-plate of 1/2-in. aluminum alloy.	Nose cap, front and rear ellipsoids 3/8-in. mild steel; tail cone of 3/16-in. aluminum alloy. E-plate 5/16-in. aluminum alloy.
Ballistic shape	See Section D	See Section D
Vibration transmission	Vibration in outer case transmitted through damping mass of sphere to electrical components.	Vibration damped by same method, except A-plate in Mod 0 which is mounted directly to case.
Sealing	Done by internal gaskets.	Done by external tape.
Accessibility to all detonators	Requires removal of antenna noseplate, split band, rear cover plate, and cartridge.	Requires disassembly down to sphere.
Accessibility for nuclear insertion or extraction.		
Accessibility to fuzing and firing components	Requires removal of rear coverplate and installation of cartridge tracks. Cartridge containing fuzing and firing components except antenna plate rolled into or out of rear case. Antennas are in noseplate. Access to antenna cable connectors through nose access cover plate.	Requires complete disassembly down to sphere for firing components. Requires removal of entire tail assembly for fuzing components.

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(E). ELECTRONIC CARTRIDGE

(1). Functional Use and Design Requirements

The cartridge was designed to contain all of the fuzing and firing components (Figs. 13 and 14) excepting those which must necessarily have connections directly at the skin of the bomb for external access and/or proper function. The specific items excluded are the antennas for the Archie sets, the receptacles for the safety plugs, and the receptacles for the pull-out plugs. In order to make plug-in connection to the detonator circuits possible, the distribution and cable compensation system was split from the rest of the X-Unit at the gap output in such a manner as to make connection by spring fingers when the cartridge is fastened into place. The distribution and cable compensation system is fastened to the sphere assembly, and the X-Unit is located on the front of the cartridge.

Vibration has been minimized by mounting the entire cartridge structure on the sphere assembly to damp out the vibration from the outer case. This practically dictated that the shape of the cartridge be cylindrical for greatest strength and most effective mounting.

The entire cartridge is easily removable for testing or replacement. The placement of parts on the cartridge permits all routine field tests to be made without removal of any of the components from the main structure. Components such as Archies and baro switches which frequently have to be modified or adjusted in the field under different tactical conditions, are easily removable without major disassembly.

Relatively few connections need to be made to complete the electrical hookup after the cartridge has been fastened into place, and these are easily and quickly accomplished. They include the four antenna cables for the Archies, the two safing-plug cables, the two pull-out cables, and the pull-out wire harness. No manifold pressure connections for the baro switches are required for this bomb, since the baro switches operate from the internal pressure of the bomb.

Fig. 13. -- Cartridge Containing Fuzing and Firing Components

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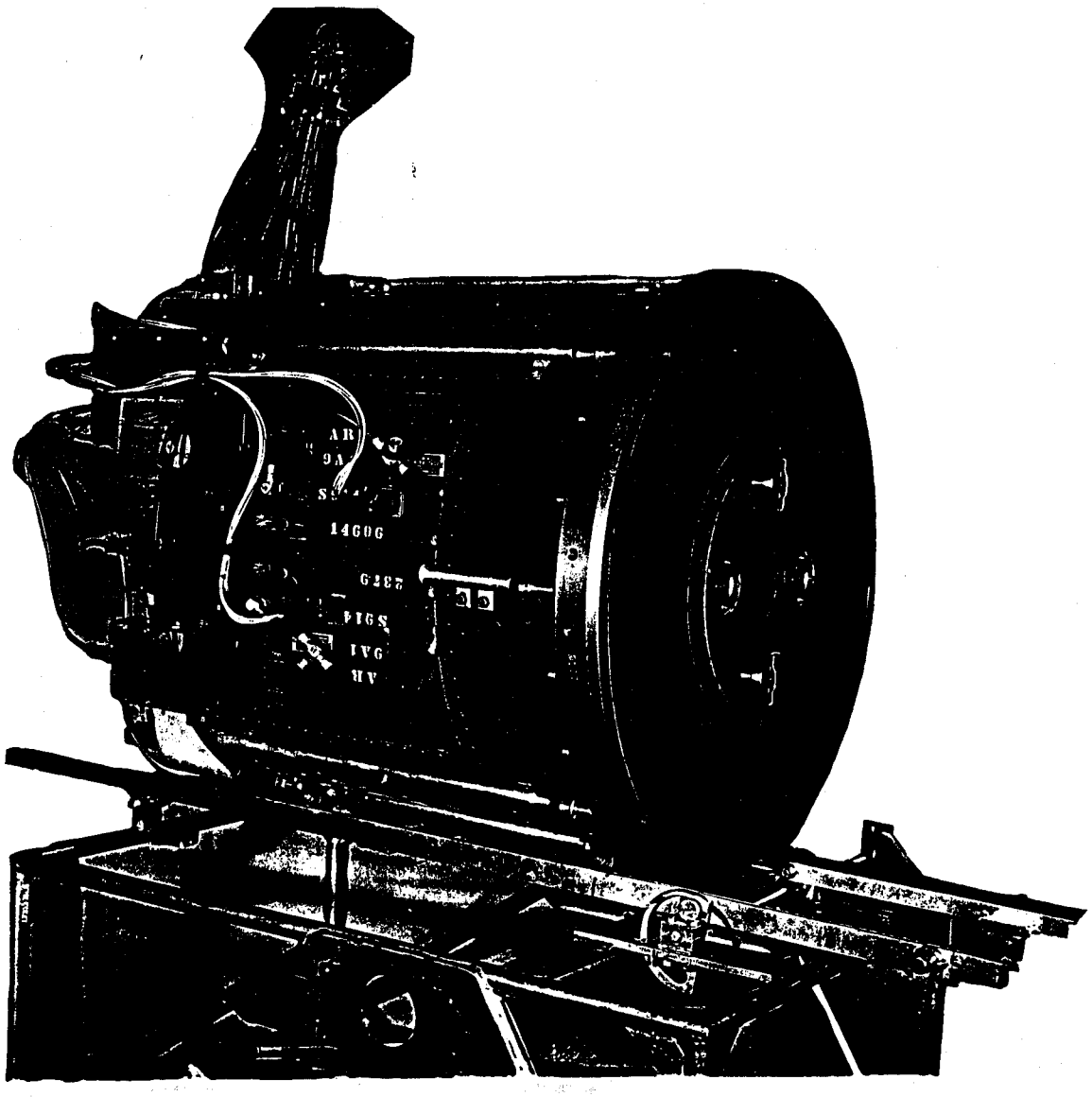


Fig. 14. -- Cartridge Containing Fuzing and Firing Components

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(2). Tests, Calculations, and Discussion

Preliminary vibration tests on a completely assembled cartridge indicated that it was not sufficiently rigid structurally. Components mounted on the free end of the cantilever experienced accelerations of several times the input to the shake table.

The cartridge case was redesigned, and the Archies were mounted for vibration isolation.[10]

Tests on the final cartridge[11] showed that the cartridge structure will withstand constant amplitude vibration from 10 to 55 cps with an acceleration of 10 g at 55 cps; the magnification ratio of the cartridge structure has been decreased considerably, and the Archie assembly has been effectively isolated from vibration.

Calculations indicate that the cartridge case and attachments of the individual components will withstand a 10-g vibratory load factor.[1]

The maximum vibration recorded for a component of the cartridge during drop tests was 1.73 g at 240 cps.[5] The amplitude of vibration for most of the drops was so small that actual values could not be obtained.

(3). Comparison With Mk III Mod 0 and Mod 1

Item	Mk IV	Mk III
Mounting of Components	All electrical components except the Archie antennas and firing distribution system are mounted on a plug-in cartridge case. The entire cartridge case is mounted on a sphere to damp out the vibration from the outer case and is easily removable for testing.	Mod 0: Firing set is mounted on the forward cone which is attached to the sphere. The auxiliary equipment for the firing set mounts on the flat plate (A-plate) attached to the forward ellipsoid. Fuzing equipment is mounted on the flat plate (C-plate) which is attached to the rear cone. The rear cone is attached to the sphere. All components except those on the A-plate are mounted on the sphere to damp out vibration from the outer case. Mod 1: Same type of mounting as Mod 0, except that the A-plate does not exist in this model.

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Item	Mk IV	Mk III
High-Voltage to Detonator	Connections to detonator are made by bayonet-type pressure connectors. All detonator cables terminate in a distributor flange mounted on the sphere. The distributor flange is the receptacle into which the fuzing and firing cartridge fits after assembly to the bomb. The detonator circuits are automatically completed to the X-Unit by spring fingers when the cartridge is inserted. NOTE: This makes it possible for the first time to have detonator wiring done before installation of the firing set, and allows the fuzing and firing set to be removed from the bomb without a major disassembly.	Mod 0: Connection to detonator made by crimping coaxial cable to detonator lead. All detonator cables terminate at the X-Unit in spark-plug connectors; all calbes must be attached to the X-Unit before any of them can be attached to the detonators. Mod 1: Connection to the detonator is same as Mk IV. All detonator cables terminate at the X-Unit load rings in a preformed, removable harness which must be attached to the X-Unit before assembly. The X-Unit must be installed before the detonator connections can be made.

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Fig. 16. -- Mk IV X-Unit

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The mechanical specifications for this set require ability to operate under defined conditions of vibration, temperature, pressure, and humidity. The vibration specifications require vibration cycling from 10 to 55 cycles per second in one minute, with a total displacement of 0.06 inch for 45 minutes along each of the three major axes. The temperature specifications require operability of the set over the range from -22°F to +149°F. The pressure specifications require operation of the set in a normal manner at pressures as low as 7.0 psi (approximately 19,000 feet altitude). The humidity specifications require operability at humidities from 80 to 90 per cent RH at 79°F, approximately.

The X-Unit is armed by a network of clock-operated switches set to operate approximately 15 seconds after the pull-out of the arming wires. These arming wires are pulled as the bomb drops away from the plane.

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[redacted] This assembly differs from the Clock-Bank Assembly used in the Mk III Mod 1 only in the orientation of the connectors.

The Clock Assembly, housed in a Fiberglas laminate shell which serves as a heat insulator, is recessed into a central compartment of the Junction Box. The mechanism is maintained at proper operating temperature by two thermostatically controlled heater strips which are connected to the plane's power source through the FTB. Each heater strip and thermostat forms an independent heating device which cuts in at 80°F and out at 100°F.

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[redacted]

(b). Fuzing System

The fuzing system uses the same general components as were used in the Mk III Mod 1 bomb, but these components are remounted to conform with the cartridge design concepts. The fuzing system in the Mk IV Mod 0 bomb includes four Archies, six baro switches, two relay networks, and one (slot) antenna noseplate. The Archie is the same modified tail-warning radar set, the APS-13, used as the basic fuze in previous atomic bombs. The relay networks are so arranged that any two Archie output signals will operate both relay networks. Each relay network is in itself capable of firing both channels of the X-Unit.

In order to protect the Archie sets from damage due to shock and vibration, they are placed on vibration isolation mounts in the Cartridge structure.

The antenna system consists of four cavity-backed slot antennas mounted symmetrically on the front noseplate. The flush-mounting slot antenna is superior from an aerodynamic and handling standpoint to the Yagi-type antenna used on previous bombs. Electrically, the slot antenna has the desirable characteristics of broad band, low-voltage standing wave ratio (1.5 or less in the normal operating range),

suitable radiation pattern, and gain comparable to the former Yagi antenna. The noseplate assembly weighs 62 pounds. A design is now under development that will reduce this weight to approximately 15 pounds.

The baro switches are the same (BS-4 and BS-5) as those used in previous bombs and have the same function.

In the Mk IV Mod 0 weapon the pressure that actuates the baro switches is obtained by a flow of air into the interior of the bomb through six 3/8-inch ports near the nose. Since the bomb case serves as a manifold, no hose connections to the baro switches are necessary. The pressure drop across the ports produces nearly ambient pressure inside the bomb

(c). Junction Box

Excepting the antenna cables, all fuzing and firing system interconnections are made through the Junction Box. The use of the Junction Box makes it possible to disconnect any of the major subassemblies for replacement or modification without a major disassembly of the cartridge. The Junction Box contains the Archie integrating capacitors, the relay networks, the power fuses, and the pull-out switches. The pull-out switches are so mounted that pull-out wires can be inserted without removal of the Junction Box cover.

(d). Power Supply

The power supply for the Mk IV Mod 0 bomb consists of two independent banks of 30-volt lead-acid batteries contained in one heated enclosure. It is identical to that used in the Mk III Mod 1 bomb. The batteries, designated ER-12-10, are markedly superior to the NT-6 batteries used in the Mk III Mod 0 bomb. They have a longer shelf life in a charged condition, greater mechanical ruggedness, and require simpler preparation and installation procedures during weapon assembly operations.

(e). Safety Features

Adequate safety features are included in the design of the electrical system to prevent premature detonation under all predictable circumstances from the time of assembly until the baro switches close (normally a few seconds before detonation altitude).

Protection from the time of assembly until the firing plugs are inserted is afforded by safing plugs in the nose of the bomb. These safing plugs open the power lines to the firing set, and, in addition, short-circuit the input lines to the firing set. Protection during the remainder of the time the bomb is in the plane is afforded by a bank of clock-operated switches which provide an open circuit to the firing set, and by pull-out switches which provide open circuits from the relay network outputs to the firing switches.

Protection from time of release until the bomb is out of fuze range of the strike aircraft is afforded by the X-Unit arming clocks and barometric switches.

In the event of premature baro-switch closure, the arming clocks will prevent the X-Unit from firing should the radar fuze range on the plane. Normally, the baro switches prevent the radar fuze from operating during this period.

Protection against premature detonation after operation of the clock switches is afforded solely by the baro switches. They minimize chances of premature fuze operation due to malfunction of equipment and radar countermeasures.

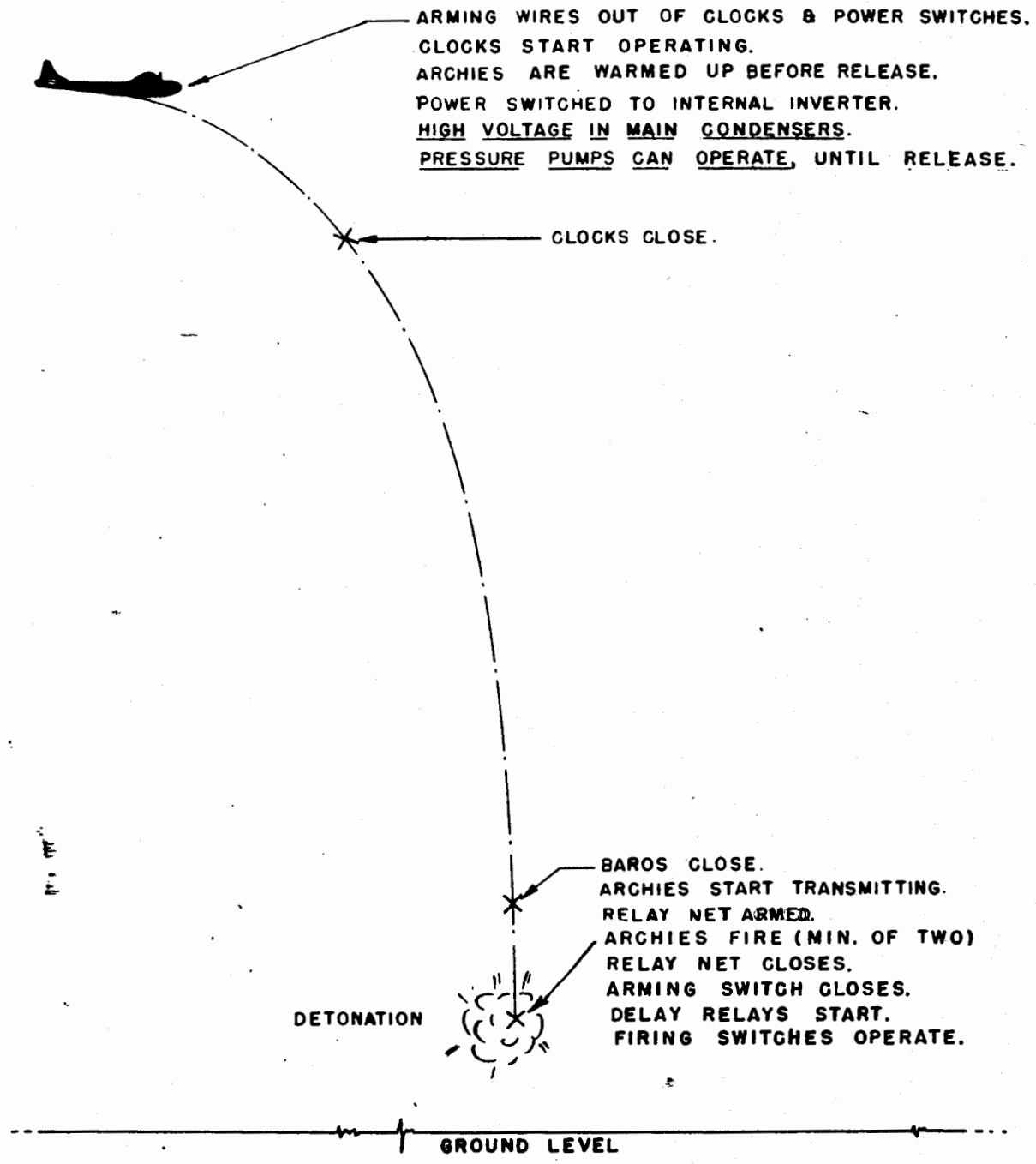
(f). Comparison of Drop Sequence of the Mk III Mod 0 and the Mk IV

Operating phenomena after release are provided in Figures 17 and 18. There is no significant difference in this respect between the Mk III Mod 1 and the Mk IV.

(2). Tests, Calculations, and Discussion

(a). Firing System

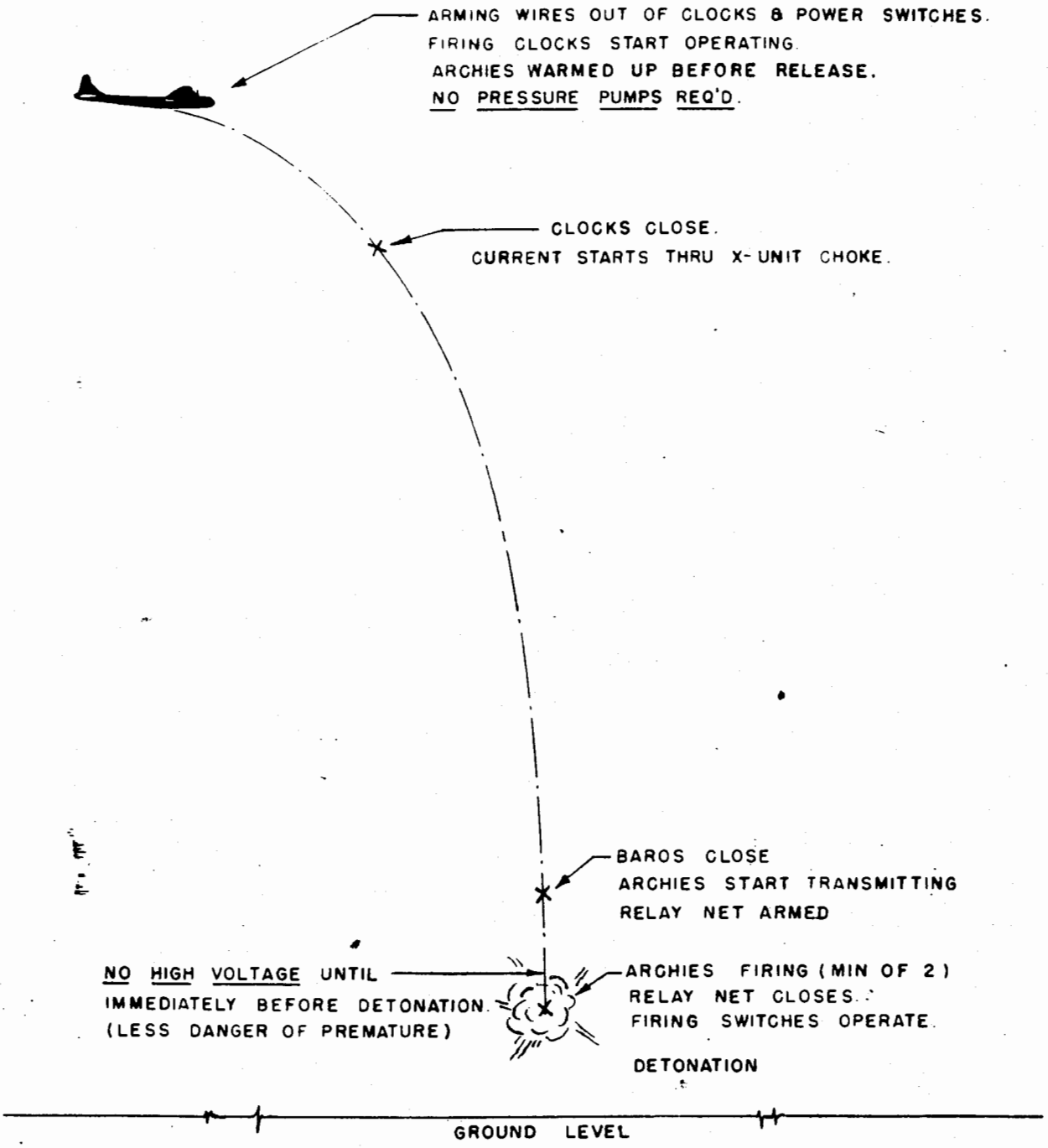
The X-Unit Mk IV Mod 5 has successfully operated under all conditions of temperature, pressure, vibration, and humidity mentioned above on page 58[12,13].



DROP SEQUENCE FOR THE 1561 FM ATOMIC BOMB
WITH THE MK. II X-UNIT
(MK. III MOD. 0 ATOMIC BOMB)

FIGURE NO. 17

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DROP SEQUENCE FOR THE MK IV, MOD 0 ATOMIC BOMB

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FIGURE NO. 18

Several pulse transformers were tested thousands of times with 1.5 watt-seconds of energy; 1.2 watt-seconds is typical of X-Unit usage. No failures resulted.[14]

Firing Switch Vibration Tests. -- The firing switch, in its enclosure, was vibrated at 10 g from 30 to 200 cps.[15] Trouble with contact chatter was encountered at higher frequencies, but operation was normal at accelerations well above those met with in drop tests.

X-Unit Condenser. -- Condensers have passed a 17-kilovolt high-potential test at temperatures as low as -70°F.[16]

[redacted]

These results have been verified at Los Alamos by GMX-7 through an explosive mixture similar to that used in the 1E20 detonator (Ref GMX-7-30, Mk IV Mod 5 X-Unit Firing Tests, August 16, 1949).

Clocks. -- The modified M-111A2 fuze is capable of withstanding a vibration of 10 g at 10 to 55 cps in three planes for 45 minutes. Operation was not affected by exposure to 120°F, 98 to 100 per cent RH for 48 hours, with subsequent lowering of temperature in decrements of 5° per minute to 25°F. The main weakness of this clock is that it is neither rewindable nor resettable without special procedures, including the taking of X-ray pictures. This, coupled with a total life of approximately five operations, prohibits field testing and makes operational testing by the Road Department impracticable. This timing device is not suited to long-term storage because (a) it must be stored in wound condition, which may result in a weakening of the untempered main spring; (b) the lubricant becomes viscous during long-term storage; and (c) not all parts are corrosion resistant.

(b). Fuzing System

Archie Tests. -- Normally-mounted Archies were vibrated in a cartridge for 45 minutes in the two most severe planes. Maximum acceleration at the base of the cartridge was 10 g at 55 cps. No mechanical failures occurred, and the Archies were electrically operable at the conclusion of the tests.[11]

(3). Comparison With Mk III Mod 0 and Mod 1 FM

Item	Mk IV	Mk III
(a). X-Unit Note: Mk IV X-Unit is essentially a re-packaged version of the X-Unit used in the Mk III Mod 1 bomb. The clock enclosure and the battery box have been removed from the X-Unit and located elsewhere on the cartridge.	Charges a condenser from 30-v d-c source to high voltage by means of a resonant charging circuit.	Charges condenser to high voltage from 30-v d-c source by means of 400-cycle inverter, step-up transformer and rectifier.
	Energy to fire detonators stored in magnetic field prior to operation of firing switch.	Energy to fire detonators is stored in condenser bank charged to high voltage before operation of firing switch.
The unit has been designed to save weight and bulk. The wiring of the unit has been considerably simplified.	The X-Unit is armed by two banks of clock-actuated switches, started by pull-out wires, one bank per circuit, two per X-Unit.	Iris-type arming switch is actuated by relay net. 12-v d-c winding is operated at 30-v d-c for rapid action and positive hold-down. Two switches are provided per circuit, four switches per X-Unit.
The remarks in the "Mk III" column pertaining to the X-Unit refer only to the Mk II X-Unit that is used in the Mk III Mod 0 FM unless specifically mentioned otherwise.	The firing switch is a high-speed switch operated by the impact of a rotor. This provides nearly instantaneous opening of the switch to cause the sharp voltage rise that is desired in the firing condensers. It is operated by Archies after gate formation. Delay Relay is not required. No interlock is required because the arming switch must be closed before any power is available to the choke, which is the only source of high potential. Consequently, if the firing switch did operate prematurely for any reason (highly improbable), no firing would result as long as the arming switch was not first actuated.	Firing switches, two per X-Unit, one per each circuit, are operated by Delay Relays which are started by Archie relay net. The Relays prevent too early a closure. An interlock (electrical) prevents the closure of firing switch before arming.

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Item	Mk IV	Mk III
(a). X-Unit	The Mk IV gaps have a radioactively stabilized breakdown voltage; hence are more uniform in characteristics than those in the Mk II X-Unit. These stabilized gaps are used as voltage sensitive switches to fire detonators automatically when sufficient voltage exists. [redacted] b(3) DoE	The Mk II X-Unit gaps do not require special stabilization of the breakdown voltage, since their breakdown is normally forced by a trigger pulse applied simultaneously to a special electrode in each gap when a firing switch operates. [redacted] This, plus a bias stabilization system for the trigger electrodes, insures that no gap will break down without a normal firing switch operation. b(3) DoE
	Premature gap breakdown is not possible as previously explained under firing switch above. The high potential needed for firing the detonators is not present until the firing switch is operated by the final Archie signal. Firing condensers are shorted and grounded until the firing switch opens.	Premature gap breakdown is unlikely as indicated in the preceding paragraph. Measures have been taken to insure that even an improbable premature gap failure will not fire the detonators. An arming switch for each gap opens the circuit to the detonators, and also grounds the input to the detonator cables. In addition an electrical interlock between the arming and firing switches prevents triggering of the gaps prematurely.

[redacted]

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Item	Mk IV	Mk III
(a). X-Unit	Because high voltages are not present at high altitudes, no pressurization of the X-Unit is required to prevent flash-overs. The whole system provides safety through simple circuitry.	The Mk II X-Unit case must be pressurized in the bomb bay and during the drop to prevent flash-over of high voltage at high altitude. Unit has high voltage present both in the airplane and during the drop.
	Only moving parts are the magnetically operated firing switches (2).	Moving parts are the magnetically operated arming switches (4) and firing switches (2).
	Open framework construction.	Unit sealed and pressurized.
	Very simple circuitry, containing only essential operating elements.	Circuitry quite involved.
	Weight of X-Unit 335 lbs approximately.	Mod 0 FM - 300 lbs approximately Mod 1 FM - 700 lbs approximately (with full batteries).
(b). Archies	Either X-Unit spark-gap switch fires all detonators.	Each spark-gap switch fires only half of the detonators.
	Archies are antivibration mounted.	Archies are not antivibration mounted.
(c). Barometric Switches	Same as used in Mk III.	BS-4 and BS-5.
(d). Barometric Switch Pressure System	Baros are open to the interior of the weapon. Pressure for operation of the baros is obtained by a flow of air through six port openings and desiccators located approximately 1/2" aft of the flat nose of the weapon.	Baros are connected to an annular manifold which is in turn connected to eight holes located about 30 inches aft of the maximum diameter of the bomb.

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Item	Mk IV	Mk III
(e). Junction Box	Archie outputs are connected to two hermetically sealed relay networks. Each relay net output is connected to one firing switch.	Archie outputs are connected to a single relay network with a common output. This common output is connected to both firing switches.
	Pull-out switches can be armed with pull-out wires without removing the Junction Box cover.	The Junction Box cover must be removed to allow arming of the pull-out switches with pull-out wires.
(f). Pull-out Wires	A single pull-out wire seal assembly, fastened by three screws, is used to pass the ten pull-out wires through the rear case.	Five pull-out wire assemblies, each fastened with four screws, are used to pass the ten pull-out wires through the ellipsoids.
(g). Pull-out Cables	2 required for monitoring of electrical equipment during flight.	Mod 0 FM - 6 required. Mod 1 FM - 3 required.
(h). Archie Antennas	Uses 4 slot-type antennas flush-mounted on a single flat plate which serves as the noseplate for the weapon.	Uses 4 Yagi-type antennas that are mounted on and protrude from the ellipsoids. To prevent mechanical damage to the antennas and for security reasons, it is desirable to mount them after the weapon is loaded into airplane.
(i). X-Unit Clock Bank	Same as Mk III, but mounted in Junction Box assembly.	Mod 0 - None used. Mod 1 - 8 M-127 flare fuze clocks placed in one heated enclosure, 4 clocks per bank, 2 banks. Mounted in X-Unit assembly.

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Item	Mk IV	Mk III
(j). Battery Box	Same as Mk III, but located on rear plate of cartridge.	Mod 0 FM - One heated enclosure for fuzing equipment with four 30-v banks of batteries located on C-plate. One heated enclosure for firing equipment with two 30-v banks of batteries. Located on A-plate Mod 1 FM - One heated enclosure with two 30-v banks of batteries. Located on X-Unit.

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(J). NUCLEAR COMPONENTS

(1). Functional Use and Design Requirements

The purpose of the nuclear components is to release rapidly a large quantity of energy through the fissioning of a core of U-235 and/or Pu. The energy is released as a result of the rapid rise of the neutron population in a highly compressed supercritical system of fissionable material surrounded by a neutron reflector or tamper. Since the

[redacted]

energy release which causes the active material and tamper to expand and thus become a subcritical system.

The basic design which determines the size and arrangement of the various nuclear components is the product of a large number of calculations and experiments which consider, among other things, the hydrodynamics of the imploding system, the neutron properties of the active material and the tamper, and the nuclear safety problems associated with handling the fissionable material.

The engineering design must primarily consider (1) maintenance of symmetry in the assembled nuclear system with a minimum of cavities, protuberances or other perturbations; (2) fabrication problems associated with the rather uncommon materials used: and (3) requirements for ease of insertion and removal of the nuclear capsule.

(2). Tests, Calculations, and Discussion

[redacted]

(III). BOMB ASSEMBLY AND TEST EQUIPMENT

(A). Functional Use, Design Requirements, and Discussion

The equipment required for handling, assembling, and testing the Mk IV Mod 0 FM is divided into Types 1, 1A, 2, 3, and 4 in such a manner that all necessary bomb operations can be efficiently performed. Types 1 and 1A, 2, 3, and 4 have been given contracting names, ie, "kits," "lots," "groups," and "sets," respectively.

(1). Type 1 - Field Equipment - Kits. -- Type 1 equipment is divided into kits which contain the tools and equipment required by assembly teams for field assembly and field testing of the bomb and minor maintenance of test equipment. These kits are the following:

(a). Cartridge Test Kit - 40A

The Cartridge Test Kit contains all test equipment, tools and auxiliary equipment required for the complete testing of the fuzing and firing components of the bomb. The major items in this kit are a Flight Test Box, Delta Timer, Peak-Reading Voltmeter, Archie Test Panel, Baro Switch Tester, Junction Box Tester, Flight Circuit Tester, High Potential Tester, Unit Tester, Meter Calibrator, and Cartridge Dolly.

(a). Lot 40 I

The contents of this lot have not yet been definitely determined, but it will contain items such as a dispersal cradle for supporting the bomb prior to loading into the strike aircraft, and a Flight Test Box which is installed in the strike aircraft for flight check of the bomb.

(b). Lot 40 T

[redacted] b(3) DOE

(4). Type 3 - Base Equipment - Groups. -- Type 3 equipment is divided into groups which contain tools and equipment required at bases for major disassembly, long-term surveillance, and major maintenance. Base equipment will not be used for field assemblies. The various groups are the following: Group K: Canning; Group R: Nuclear; Group U: Instrument Repair; Group V: Electrical; and Group N: Mechanical.

(5). Type 4 - AFSWP Support - Sets. -- Type 4 equipment is divided into sets which contain items of support equipment for the military field organization such as material for shelter, power, disaster cleanup, and expendable stock. It will be the responsibility of the using forces to determine and procure most of the items in these sets. The various sets are the following: Set J: Expendable Stock; Set L: Heavy Tool; Set W: Disaster; Set X: Salvage; Set Y: Building; and Set Z: Power.

(B). Comparison with Mk III Mod 0 Bomb

The following list shows the comparative number of items required for assembly and testing. Owing to changes in kit philosophy the number of items may change, but their relationship will remain approximately the same.

	Mk IV		Mk III Mod 0	
	Total Items	Special Items	Total Items	Special Items
Mechanical Handling and Assembly Equipment				
Field Mechanical Kit 40F	79	25	115	36
Electrical Test Equipment				
(a). Cartridge Test Kit 40A	82	21	179	34
(b). Battery Kit 40C	28	2	48	7
(c). Test Equipment Repair Kit 40Q	Same as Mk III Mod 0			
Nuclear Test and Assembly Equipment				
(a). Nuclear Field Kit 40S	Same as Mk III Mod 0			
(b). Nuclear Flight Insertion Equipment Lot 40T	Not yet determined		4	Not used with Mk III Mod 0
Miscellaneous Equipment				
(a). Expendable Set J (b). Heavy Tool Set L (c). Disaster Set W (d). Salvage Set X (e). Building Set Y (f). Power Set Z	Little change from the kits already established for the Mk III will be required.			

(IV). SUMMARY

The Mk IV Mod 0 FM is an implosion-type atomic bomb based upon the same basic nuclear fission principles as the Mk III FM. It incorporates an improved fuzing and firing circuitry over that in the Mk III Mod 0 weapon and the same basic circuitry as that in the Mk III Mod 1 weapon. The bomb is re-engineered to provide for greater ruggedness, greater dependability, easier field techniques, and better ballistic performance than either of the Mk III versions.

The ballistic design is the result of over 100 full-scale and half-scale drop tests, including 29 drops of the final design in addition to wind tunnel and range-fired 20-mm model tests which showed good correlation to the drop tests. Values of pitch and yaw for B-29 conditions are less than 6 degrees maximum included angle, and dispersions due to the bomb itself are less than one fourth of those of the Mk III FM.

The basic elements of the fuzing system (baro switches, Archies, and clocks) have not been changed at this time, but details of the Junction Box, including the relays and pull-out switches, have been redesigned and improved. The mounting of all components has been improved to minimize the possibility of damage or malfunction. The firing set (X-Unit) has been completely re-engineered for compactness and ruggedness. All electronic equipment has been tested in the laboratory and these tests have been supplemented by 30 functional drop tests.

The field assembly and electrical checking operations that will be required on the bomb have been minimized:

[redacted] b(3) DOE

(V). CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the Mk IV Mod 0 FM implosion-type atomic bomb is an improvement over its predecessors, the Mk III Mod 0 FM and the Mk III Mod 1 FM, in the following respects:

(1). It requires less time, fewer men, and less auxiliary equipment in the field to prepare the bomb for delivery.

(2). It adapts itself to safer delivery tactics inasmuch as (a) the nuclear material may be inserted after the strike aircraft is airborne, and (b) high voltage is not present in the firing circuit until the firing switch is actuated (this is also true of the Mk III Mod 1 FM).

(3). It contains many improved components specifically designed or arranged to operate and withstand storage under stringent environmental conditions.

(4). It has improved ballistic stability and accuracy.

On the basis of these conclusions it is recommended

(1). That this weapon be produced and stockpiled as a part of the national defense program;

(2). That it replace the Mk III weapons now in stockpile;

(3). That laboratory and field investigations of all components be continued in an effort to establish more firmly the reliability and safety factors as well as the limiting environmental conditions of operability; and

(4). That a continued program of component development be pursued for the purpose of incorporating desirable modifications into stockpile weapons in the interest of military effectiveness.

(VI). FUTURE PROGRAMS FOR THE MK IV FM

The report thus far has dealt with the description and evaluation of the Mk IV Mod 0 FM weapon as it is going into stockpile. Inasmuch as progress in the field of weapon design is made a step at a time, it is planned to continue a development program on this weapon to incorporate new component improvements and features now thought to be desirable. These fall into two main groups, each of which may require a Mod change of the bomb.

(A). Lightweight Outer Case

[redacted] b(3) DOE

be possible. ~~This change~~ in case design will sacrifice all protection of the unit from low-velocity fragments, but the weight saving will materially reduce take-off hazards and permit an increase in aircraft range or speed. It will probably bring about fairly radical changes in handling techniques and equipment. This design program is now under way.

(B). New Electronic Cartridge

The second program encompasses the redesign of the electronic cartridge to provide a more reliable fuzing system. Several radar fuze devices and a new baro switch are under development at the present time. (It is planned to incorporate selected ones of these individual components into a new cartridge.)

One feature of this new cartridge will be in-flight setting of the fuzing system (specifically, of baro switches and radar units).

New clock timers and new baro switches are being developed to replace these present items in the Mk IV Mod 0 should it be judged economically and tactically desirable when the development is complete. Work is in progress to develop a lightweight and quickly detachable antenna nose-plate and sphere trap door to facilitate in-flight nuclear insertion. A new plug-in type of delay line has been developed for Archie. This modification will reduce the possibility of multiple gating, allow easier range modifications, and provide a higher maximum range setting. It is planned to replace the present Archies with the new unit, pending laboratory and drop tests.

Three other programs are being carried forward as essential improvements to the Mk IV Mod 0 to be included when the need for them is firmly established:

(1). Improvements to the present baro system.

(2). Improvements of the present split-band gasket.

(3). Solutions to the problem of the sticking of the HE trap-door charges.

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HISTORY OF THE MK 5 WARHEAD (U)

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SECRET

With the approach of World War II, both the German and Russian rocket programs became enveloped in secrecy. The next reliable information was received by the West when the Nazi V-1's (and later the V-2's) began to bombard London. This effort was not small. Dr. Walter R. Dornberger, who was in charge of the V-2 program and retained meticulous records of the activity, disclosed after the war that 5085 V-2's were build and 3578 launched.[1] After the end of the European phase of World War II, many German rocketry experts were captured by the Russians, forcibly removed to Soviet territory along with the tools and equipment of their trade, and their lore and experience added to that of the Soviets.

The United States had used small solid-propellant rockets in the Pacific phase of the war, with ship-launched rockets being employed as "softening-up" devices prior to Marine landings on Japanese-held islands, and hand-held Bazookas being used in the attack of enemy strongpoints. No heavy boosters or liquid-motor rockets had been developed, however, and the field of use of these devices was felt to be small.

Postwar experimentation at the White Sands Proving Ground in New Mexico with a captured German V-2 brought the United States to the realization that this liquid-motor device, capable of a velocity of 3600 miles per hour and a range of 100 miles, was worth developing. The Air Force established the Rand (research and development) Project under the aegis of Douglas Aircraft Company in early 1946, and the first study produced by this group described a satellite vehicle using liquid fuel and multistage rockets. Dr. Theodore von Karman, one of the organizers of the Rand Project, subsequently surveyed the state of the art in Europe and came to the conclusion that the best method of increasing the range of the V-2 was to provide a set of wings for the missile. The United States elected to follow this course, which led to consideration of pilotless bombers flying at relatively low altitudes, and development of air-breathing missiles rather than pure rockets, which were self-contained and could operate outside the atmosphere.

The success of the Germans in developing the V-missiles and the later appearance of the atomic bomb led observers to believe that a quick "marriage" of the two would follow and inaugurate an era of "pushbutton warfare." Such estimates failed to evaluate properly the complexities attendant on the development of each device and the relatively primitive state of each.[2] Lacking were such factors as reliable guidance systems, competent propulsion systems, shock-resistant warheads, and the high-quality, or "clean-room," type of manufacturing facilities yet to be developed. However, early military characteristics for an air-to-ground missile had been proposed by the Army Air Force October 19, 1945, envisioning a warhead 60 inches in diameter, 130 inches long, and 11,000 pounds in weight (in obvious reference to the Fat Man bomb), although missiles capable of carrying a warhead of this size and weight would not be available for several years.

In March 1946 the Army Air Force directed the Air Materiel Command to develop an experimental missile, and this project was given a code name of MASTIFF.[3] At the time, little information regarding MASTIFF was made available to those working on the atomic bomb, but in one of his last actions, December 12, 1946, as head of the Manhattan Engineer District and prior to AEC assumption of control, Brig. Gen. Leslie R. Groves informed the Los Alamos Scientific Laboratory concerning the project, and stated that it envisaged installation of an atomic warhead in an air-to-ground guided missile.

This information was referred to the Z Division on January 10, 1947, with a request that preliminary analysis be made, but that any sizable amount of development work be deferred until later in the year when the work load was expected to taper off.[4] Subsequently, little was done on the project in either AEC or military circles beyond a general study that contemplated use of a plane-launched drone which would glide 300 miles to a target at a speed of 300 miles per hour. However, a drone with this speed was felt to be highly vulnerable to antiaircraft fire, and the existing scarcity of nuclear material, together with the inaccuracy of drone control systems, caused apprehension that an atomic weapon might be used to bomb some unoccupied field. In mid-1947, missile development for the MASTIFF project

was assigned to Bell Aircraft Company, and was rescheduled as a long-range project to be preceded by SHRIKE, a 100-mile-range supersonic missile on which Bell had been intermittently engaged since 1945.

Subsequently, budget cuts in the 1946-1949 period reduced military participation in missile work. A 3-year period of recuperation, starting in 1950 and caused by the Korean War, partially restored financial support, but another retrenchment was made in 1953. It was not until 1956 that the missile program was consistently funded. Due to this early uncertainty, the Military gave preference to those devices which promised to reach production with the least expenditure of time and money. This generally relegated long-range missiles (which were those best suited to carrying atomic warheads) to low-priority status during the period.

The Division of Military Application notified the Military Liaison Committee, April 29, 1949, that some guided missiles being developed might reach a stage in the not too distant future where the desirability of employing them in conjunction with an atomic warhead should be considered.

This led to the establishment, June 21, 1949, of an Ad Hoc Committee, to consider the general problems of developing atomic warheads for guided missiles, and which reported to the Secretary for Defense. This Committee consisted of Lt. Gen. J. E. Hull, Director of the Air Force Weapons System Evaluation Group; Dr. F. L. Hovde, President of Purdue University; and Dr. N. E. Bradbury, Director of the Los Alamos Scientific Laboratory. This committee was to assess the possibilities for developing, within the next 5 to 10 years, guided missiles that might carry atomic warheads, and analyze the possible application of existing atomic weapons technology to the development of such warheads.[5]

The Ad Hoc Committee subsequently reported that Service requirements for a guided missile with an atomic warhead could be met within a reasonable time. It was concluded that four missiles could be adapted, with reasonable technical effort, to carry atomic warheads. These were the HERMES A-3 of

Subsequently, separate conferences were held with the three Services and Sandia Base representatives of the Armed Forces Special Weapons Project. These conferences explored the details of weapon-missile relationships, placing emphasis on Mk 5 and Mk 8 Warheads.

The Sandia Weapons Development Board provided a common forum for designer and user of atomic weapons and, in a meeting June 21, 1950, agreed to accept responsibility for coordinating guided-missile and atomic-warhead development. The Board proposed that a strong missile subcommittee be formed, but temporarily deferred appointments to this subcommittee, pending arrival of new officer assignments at Sandia and Kirtland Air Force Bases.[8]

The Division of Military Application had noted, in a letter dated June 14, 1950, that some controversy had arisen over the subject of responsibility for warhead fuzing. Army Ordnance had assumed that the Atomic Energy Commission would handle fuze development, but the AEC felt that the fuze characteristics would be strongly affected by missile operation and environment, and therefore the fuze should be designed by the missile agency.[9]

This subject was discussed in the June 21, 1950, meeting of the Sandia Weapons Development Board. One proposal was that the AEC provide funds for fuze development and retain nominal control of the project, with the work being accomplished by Army Ordnance or missile contractor. The Board in general felt that the missile was simply a carrier, that it replaced the aircraft carrying bombs, and that the fuze was part of warhead development. However, it was recognized that there was no easily defined line of demarcation between warhead and missile (such as between bomb and bomber), and the eventual ruling was that a decision on fuzing design responsibility would be made for each individual missile-warhead project. The Board proposed that AEC budget for fuzing development costs in the immediate future and that these funds be allocated to the military or AEC contractor assigned responsibility for fuze development.

On October 1, 1950, Project E, Department 1270, was established at Sandia Corporation under the jurisdiction of the Director of Engineering. The task of this Department was to study the problems of integrating atomic warheads with guided missiles. A year later, this organization evolved into Engineering II, the guided-missile Directorate.

The Division of Military Application agreed, October 10, 1950, that the AEC would accept budgetary responsibility for all guided-missile warhead fuzing with coordination of each fuze development program being subject to recommendations of the Sandia Weapons Development Board, and that requirements for an air-burst gun-type warhead were deleted.[10]

A Guided Missiles Committee of the Sandia Weapons Development Board was appointed and initially met October 16, 1950. The committee discussed accelerations, vibrations, and general environmental conditions which would be experienced by guided missiles, and concluded that these could be withstood by atomic warheads. The Committee proposed that a separate Ad Hoc Working Group be established for each missile-warhead marriage program, with the group proposing technical solutions to problems encountered in the programs.[11] The Board approved this suggestion, and these Ad Hoc Groups became a standard and important part of the missile program.[12]

The Committee also felt that specific fuzing systems for guided missiles would have to be developed, but that it should be initially possible to modify bomb fuzing systems.

DOE b(3)

It would be necessary to spell out carefully the relative priorities of the various programs, and the Committee felt that the current list of missiles should be considerably reduced in number. This list had been constantly changing, with the CORPORAL and SNARK being temporarily deleted, and additional versions of the HERMES, the RIGEL, NAVAHO, and TRITON being added.[13]

involved, that of ballistic (where the missile was launched upward and then fell into a target) and that of release from a carrier downward onto a target.

The Division of Military Application notified the Military Liaison Committee, January 19, 1951, that increasing requirements for various combinations of missiles and warheads had reached the point where standardization of warhead design was becoming difficult, if not impossible, to achieve. It was felt that the design of the Mk 5 and Mk 7 Warheads had progressed to the point where these warheads could be proposed for marriage with missiles and eliminate any need for alternate warheads.[16]

A nomenclature system having the prefix "XW" to identify warheads under design, similar to the "TX" identification for bombs, was authorized in mid-January 1951. This prefix was followed by the warhead identification (Mark number) and was coupled with the missile designator for complete missile-warhead nomenclature. The "X" stood for experimental, and the "W" for warhead. A typical example was: XW-5/REGULUS.[17]

Detailed design was meanwhile proceeding on the arming system. It was felt that automatic arming should be provided, which would take place only after the missile had crossed into enemy territory, and it had been proposed that the missile guidance system be used to signal this fact. However, there was such a complexity of missiles, with different guidance systems, that this was found to be impracticable. It was possible, however, to provide a system that would sense the initial missile speed, the existence of high-enough thrust for long-enough time, the attainment of sufficient altitude, and the pursuance of the correct direction. All these factors could be gaged by gyroscopes, clocks and acceleration switches, and a system could be devised to permit nuclear insertion only when all these factors had been met or exceeded. Sandia provided such a system for all missile-warhead combinations, with the gyroscope, clock, or switch shorted out when a given missile had no need to measure that particular factor.[18]

The fuze responsibility problem was again raised in the September 24, 1952, meeting of the XW-5/RASCAL Ad Hoc Working Group. Sandia and the Air Force presented opposing fuze-design proposals, and a clear-cut decision could not be reached. The problem was referred to the Guided Missiles Committee, which also could not reach unanimous decision, and it was in turn referred to the Special Weapons Development Board, where it was thoroughly discussed in a meeting November 12, 1952. The majority of the Board felt that Sandia should be assigned the fuzing task.

Meanwhile, the Air Force recommended to the Joint Chiefs of Staff that the Military be made responsible for all adaption-kit design (including that of the fuzing system) and that the interests of the AEC be confined to the design of the warhead proper. The Joint Chiefs of Staff endorsed this proposal and referred the decision through the Military Liaison Committee to the Division of Military Application. The DMA received this directive at almost the same time that it learned of the Board decision to assign the RASCAL fuzing responsibility to Sandia.

The Division of Military Application then reversed the decision of the Special Weapons Development Board, declaring, January 22, 1953, that basic responsibility for all guided-missile items of launcher, carrier, guidance, and fuzing would be assigned to the Military "... regardless of whether such parts are common to a standard rocket or missile or are required for use of the rocket or missile with a given atomic warhead."[22]

Subsequently, responsibilities of the Guided Missiles Committee were reviewed in the light of the above decision. It was decided to phase out this Committee and form new Joint Committees to replace the Ad Hoc Working Groups.[23] The major result of this change in policy was that the fuze-design responsibility was assigned to the missile contractor, who subsequently found that he could not produce fuzes with the proper capabilities within the time schedule, and who in turn subcontracted the fuze design back to Sandia.

Meanwhile, the Division of Military Application had issued a set of military characteristics September 11, 1951, covering an atomic warhead of the Mk 5 type for application to the MATADOR, REGULUS, HERMES, RASCAL, RIGEL, and

TRITON missiles. The warhead was not to exceed 44 inches in diameter, 77-1/2 inches in length, and 3000 pounds in weight.

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Nonradiating fuzes were felt to be highly desirable, setting of burst height was to be possible just prior to missile launching, and preflight checks were to be of a simple accept or reject type.

DOE b1

A variety of interpretations had previously been given to definition of warhead and warhead installation, and were standardized by the Sandia Weapons Development Board December 11, 1951. The warhead was defined as the nuclear pit and capsule, high-explosive sphere, detonators, X-unit, firing switch, nuclear insertion mechanism, and all hardware and cabling pertaining to these items. The warhead installation included the warhead, arming and fuzing system, power supply, and installation hardware. The warhead installation thus might vary for different missiles, even though the same warhead was used.[25]

The XW-5 Warhead would contain a Mk 5 Bomb implosion system, a Mk 5 Firing Set with a fast-firing X-unit and switch for contact bursts, and a new linear nuclear insertion mechanism.[26] Mk 5 nuclear capsules would be

used. This would produce a warhead 44 inches in diameter and 75-1/2 inches in length with a weight of 2550 pounds, excluding power supply, arming and fuzing, and mounting hardware.[27]

The Sandia Weapons Development Board ruled that the warhead installation should not be design released until six successful tests of the warhead in the missile had been made. Missile availability dates were still largely indefinite, but it was felt that at least 9 months would be required between design release and early production.

The Mk 5 Mod 0 Warhead was design released August 1953, and production was achieved July 1954. The warhead incorporated a linear nuclear insertion mechanism, but otherwise was identical with the Mk 5 Bomb less outer case.

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A Mk 5 Mod 1 Warhead was proposed for use with the RASCAL missile, incorporating dual-motor nuclear insertion mechanism, but was canceled during design, April 16, 1956.[28]

Investigation was undertaken of both forward extending pressure probes and trailing devices. It was hoped to develop a simple barometric fuze, but tests showed that the pressure pickups did not give reproducible results, and that the missile would have to travel faster than Mach 1.0 to prevent premature fuze operation.[32] A decision was made to use a baro-armed radar fuze, a modification of the fuze design of the Mk 5 Bomb.[33]

In early 1952 the Mk 5/REGULUS was given a higher priority than its Mk 8 counterpart, since there was a limitation in the number of missiles available for test flights.[34] Work was started on a contact fuze for several missiles, and successful completion of this task made it possible to provide the XW-5/REGULUS with two fuzing options; radar air burst with contact-fuze backup, and surface burst by impact crystals.

The Navy had requested that a pure barometric fuze be developed, and this was discussed in the June 27, 1952, meeting of the Ad Hoc Working Group. Sandia reported that this design would require an additional 10 months, and that it was not at all certain that such fuze would have the required accuracy. The Group, after considerable discussion, decided to approve the radar fuze for use in the REGULUS and to continue development of a barometric fuze.

The RAM Program (for REGULUS Assault Missile) was initiated by a letter from the Military Liaison Committee to the Division of Military Application August 18, 1952. This was a project to provide the capability for launching the REGULUS missile from a surface ship, guiding the missile to target, and arming and detonating the warhead by command from carrier-based fighter aircraft.[35]

The program was given a high priority in mid-February 1953, and a small number of Mk 5 Bombs were placed in standby storage April 1953, together with the hardware to convert these bombs to RAM installation, which had been renamed the REGULUS Interim Capability Program. These units were subsequently retired in mid-1954, as normal XW-5/REGULUS components became available.[36]

The launching action closed two pullout switches which applied power to the timer motors. At the end of 6 minutes' safe-separation time, the timer made power available. If the command arming signal bypass switch was closed, the nuclear capsule was now inserted; otherwise, receipt of the command nuclear-arm signal resulted in this operation. When the missile "dump" signal was received, voltage was made available to relays controlled by an arming baroswitch. In addition, these arming relays connected the radar arm circuits to the fuze baroswitch.

When the missile descended to a pressure altitude of about 20,000 feet, the arming baroswitch closed, starting the inverters and charging the X-unit. At an altitude 700 feet higher than the desired height of burst, the fuze baroswitch closed and armed the radars, which began transmitting and receiving. If both radars were operating properly, the X-unit was triggered and caused detonation when the second of the two radars ranged. If one radar failed to range at its preset altitude, detonation occurred 300 feet lower, when the fourth element in the fuze baroswitch closed. This element effectively switched the radar firing lines from a series to a parallel connection. If both radars failed to operate, an impact-fuze system triggered the X-unit.

For the RAM mission, special plugs were installed which allowed the X-unit to be charged when a command electrical arm signal was received from the control aircraft. Transmission of a second command caused the nuclear insertion mechanism to operate, and subsequent issuance of the command-fire signal detonated the warhead. The impact fuze provided a backup.

Meanwhile work had been proceeding on a barometric fuze design. Some progress was made and, in the Ad Hoc Working Group meeting October 7, 1953, it was decided that the remaining REGULUS flight-test missiles would be used to prove out this system, which had been given the designation XW-5/RG-X1. Authorization for this modification was issued subsequently by the AEC and design release scheduled for June 1954.

A new high-speed missile, the REGULUS II, was being developed. This would travel at twice the speed of the original REGULUS, or about Mach 2.0, and this increased velocity would more than double the ability of the missile to penetrate enemy defenses without being shot down. Test vehicles of the new design would be available by the fall of 1955, and a feasibility study was authorized by the Secretary of Defense December 1953.[38] The REGULUS II program was promoted to full-scale development stage in April 1955.[39]

Tests of the pressure-sensing system for the XW-5/RG-X1 showed that [redacted] This, however, required additional missile flights, and the design release date was postponed to January 1955.

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On August 19, 1954, the Military Liaison Committee proposed that responsibility for REGULUS adaption kits be transferred to the Navy. A meeting was held October 28, 1954, at which it was decided that this transfer would be made July 1, 1955.[40]

A production-model REGULUS, carrying a Mk 5 Warhead, was launched from the cruiser Los Angeles February 15, 1955, with the missile flight being controlled by an accompanying aircraft. Inflight insertion and command arming were accomplished satisfactorily, although the flight came to an abrupt termination when the warhead was accidentally detonated just short of the target. However, missile and warhead performance were satisfactory throughout the 23-minute flight, which covered 173 miles.[41]

Evaluation flights from submarines were largely successful. Impact tests indicated that the contact crystals generated sufficient voltage to detonate the warhead, and that this detonation occurred prior to warhead deformation. Impacts produced by travel through rain or hail, however, would not cause premature detonation. Thus, the system was given general release.

It had been suggested that the design with the barometric fuze be identified as a Mod change upon entry into stockpile. Action on this suggestion, however, was tabled pending assumption of design control by the Navy. Subsequently, it was decided that the Mk 5 Warhead would be replaced by the Mk 27, and all Sandia activity was suspended on the Mk 5/REGULUS Warhead Installation March 1, 1956.[42]

CHAPTER III

MK 5/MATADOR WARHEAD

The MATADOR was a surface-to-surface, turbojet-powered, transonic missile with a range of about 600 nautical miles. The missile was constructed in the shape of a streamlined fighter plane with an over-all length of 39 feet, maximum diameter of slightly over 4 feet, and swept-back wings. It was launched from a zero-length launcher by a single, solid-propellant rocket, which accelerated the missile until the turbojet engine could attain enough thrust to sustain flight. This rocket booster was pneumatically ejected at time of burnout.

At launch, the missile climbed to an altitude of 40,000 feet, then followed a level trajectory to a "dump point" where it pushed over and dove into the target. Two guidance systems were proposed for use, Shanicle and Marc. Shanicle used four ground stations, which generated guidance beams. The missile received these signals and converted them into azimuth and range guidance. Marc used two trailers that tracked the missile and sent command signals. When the "dive point" was reached with either system, the missile followed a programmed terminal trajectory to the target. MATADOR was designed and built by the Glenn L. Martin Company for the Air Force.

The missile was initially considered for marriage with an XW-5 atomic warhead in early 1950.[43] The MATADOR project was accelerated in late 1950, due to the situation in Korea, and on December 18, 1950, the Joint Chiefs of Staff recommended to the Secretary of Defense that a number of missile projects be approved, among them the MATADOR.[44]

Much of 1951 was taken up with consideration of the solution of general problems relating to the development of atomic warheads for guided missiles, and it was not until October 3, 1951, that an XW-5/MATADOR Ad Hoc Working Group was named by the Guided Missiles Committee and held its first meeting. The Group proposed that both radiating and nonradiating fuzes be considered,

but that--due to program urgency--the TX-5 bomb radar fuze be initially used. Several methods for warhead arming were proposed. One approach would use a clock timer in conjunction with the missile's gyro compass, and another design would incorporate command arming, using the missile's command guidance system. The first of these was felt to be the more reliable.

These recommendations were considered in the December 11, 1951, meeting of the Sandia Weapons Development Board. The Air Force would be responsible for determination of the data upon which the decision to arm or not to arm would be based, and for supplying a suitable signal to the warhead; and Sandia would be responsible for applying this signal to cause arming.[45]

The Division of Military Application wrote to the Military Liaison Committee February 4, 1952. Design release of the Mk 5/MATADOR warhead installation could not be made before February 1953, to allow sufficient time for six sytems flight tests, and production would require another year. The Department of Defense, however, had authorized substantial production of the missile for early 1952, and it thus appeared as though the nuclear warheads would lag the missile by about a year.[46] A request was made that the Mk 5/MATADOR program be expedited, but there appeared to be no way in which this schedule could be shortened.

Detailed consideration of the design in early 1952 resulted in a system that would use a timer which furnished an arming signal after the missile had crossed over into enemy territory. The guidance system would put the missile into a terminal dive if it deviated from its course. If the arming timer did not operate, no nuclear detonation would take place.

A trailing probe was tested to signal burst height by barometric means. However, this device had a number of disadvantages, including problems of storage and release after missile launch, time lag of operation, the fact that only one probe could be installed in the space available, and assembly

had been reduced in weight, and a linear nuclear insertion mechanism installed. This mechanism could be operated either by command signal or arming timer.

A heading-error device built into the missile would cause it to enter a terminal dive, should the missile flight path stray more than certain specified limits from a preset course. An acceleration switch would operate 1 second after missile launch and close a safety switch. After the arming signal was received, a "dump" signal from the missile guidance system would start the fuzing sequence and initiate the terminal dive to the target. When the missile reached a point in the dive where external pressure was equal to one-half sea-level atmosphere, the X-arm baro would close, starting two inverters and charging the firing set. At a preset lower altitude, the fuzing baro would close, placing the two radars in operating condition. These two radars would initially be connected in series, and both would have to "range" (or operate) to detonate the bomb. Slightly below the desired burst altitude, these radars would be reconnected in parallel, so that operation of either radar would detonate the bomb. The impact fuze was not yet available, but was under development, and it was hoped to incorporate it in the Mod 0.

Meanwhile, missile production difficulties were being encountered. Early missile flight tests were also unsuccessful, with the arm signal failing to operate on the first flight; the missile breaking up in the terminal dive in the second; and the missile being destroyed in the third, when it became impossible to correct a severe deviation from the planned flight path. The design-release date was postponed to June 1953.

Three flights were made during March 1953, but all were unsatisfactory from the warhead standpoint, primarily due to missile failure. The AEC stated that it appeared undesirable to continue to divert Mk 5 high-explosive components from current production for use in MATADOR flights until the missile problems were solved and, as a result, further missile flights were postponed.[51]

After missile modifications were made, successful flights were made in August 1953, and warhead installation flights were resumed September 1953.[52] A MATADOR missile with a Mk 5 Warhead was launched from the Air Force Missile Test Center in Florida November 2, 1953. It accepted no commands after takeoff, and was eventually destroyed by removing all carrier guidance and allowing the missile to dive out of control. Reports of a crash in the Bahamas led to recovery of parts of the missile, but the warhead components were never located.[53]

In spite of the lack of flight-test verification, an interim release of the Mk 5/MATADOR warhead installation was made January 1954, and Report SC2982(TR), Interim Design Status Report of the XW-5/B-61A MATADOR, was approved by the Special Weapons Development Board. Additional missile difficulties then developed, and it appeared as though the final release could not be made for several months.[54]

On February 24, 1954, the Air Force Special Weapons Center requested Sandia to provide a barometric fuze for the Mk 5/MATADOR.[55] However, by this time the Military had assumed responsibility for design of new fuzing systems, and this problem was referred to the Air Force, with Sandia services as subcontractor being offered.[56]

Operation BLACK SWAN was established in the spring of 1954. This was a MATADOR Interim Capability Program under which bomb-to-warhead conversion components were supplied on an expedited basis, and associated with five Mk 5 Bombs for use in the event of national emergency.[57] These items were retained for possible use until late 1954.

Report SC3344(TR), Description and Status Report at Design Release of the XW-5/B-61A Atomic Warhead Installation, was presented to the June 30, 1954, meeting of the Special Weapons Development Board.[58] This report was accepted, after some revisions were made to the premature figures, and transmitted to the Division of Military Application. The Final Evaluation of the Mk 5/TM-61A

Atomic Warhead Installation, SC3560(TR), was also reviewed by the Board, July 13, 1955.

DoE b(3)

The warhead, although not being truly a universal design, incorporated many components from other weapons.[59]

Some small effort was made to incorporate an XW-5-X1 Warhead containing the barometric fuze being developed by the Air Force. However, these plans were eventually dropped, and all effort ceased on the Mk 5/MATADOR project in early 1956.[60]

A meeting of Sandia and Bell Aircraft personnel was held September 19, 1950, and initial plans for a missile-warhead formulated. The first glide missile drop was scheduled for April 1951, development launches for early 1952, and interim designs of the terminal guidance system for 1953. The test program would extend to mid-1954. It was suggested that a Mk 5 Bomb with nuclear insertion mechanism and existing fuze be repackaged to suit this missile-warhead combination.

An XW-5/RASCAL Ad Hoc Working Group was appointed and initially met November 7, 1951. The objectives of this Group were to consider problems of arming and fuzing, recommend assignment of tasks, and review proposed solutions.[62] At this time the problems of fuzing atomic warheads for guided missiles had been assigned jointly to the Military and the Atomic Energy Commission by the Department of Defense.

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of this objective was not to delay the operational date of the warhead installation. Nonradiating fuzes were desirable, although radiating fuzes would be acceptable if their resistance to jamming was equal to that of an improved Abee or Albert. The missile system would provide an arming signal. A universal fuze, applicable to several missiles, was desirable. Nuclear arming was to be possible at any time during the missile flight, and external means of safing the firing system should be designed.

A study was made of possible means for retaining the nuclear capsule in the event the missile had to be jettisoned. Among the solutions proposed was a spherical clamshell and a removable door on the missile. However, there were many complexities and, as time passed, the problem of scarcity of nuclear material began to ease, and the requirement for capsule retention was dropped.

By early 1952 the design release of the warhead installation was scheduled for July 1954, early production a year later, and stockpiling by October 1955.[63] Shortly thereafter, it was felt that the program could be accelerated by about a year, due to the similarity of the design to the one already considered for the MATADOR missile.[64] The chief carriers of the missile-warhead would be the B-36 and B-47 Air Force bombers. The weapon would be carried in the rear bomb bay of the B-36, and on a pylon under the wing of the B-47.

It was proposed that Sandia design and provide the initial fuze, with a low-altitude fuze study being conducted by both Sandia and Bell Aircraft. Details of the Sandia fuzing system were discussed in the September 24, 1952, meeting of the Ad Hoc Working Group. Sandia advocated the use of a radar system, noting that jamming of these radars would be difficult and expensive. The Military desired a nonemanating fuze, and felt that the system should be of this type. Sandia agreed to develop both systems, with emphasis on a baro-fuze approach.[65]

The Military then proposed that the entire arming and fuzing task be assigned to the Air Force, since they felt that this system and the missile were closely interrelated.[66] This proposal was approved by a majority of the Group and referred, through the Guided Missiles Committee, to the Special Weapons Development Board.[67] The Board agreed that it would be desirable to develop a barometric fuze, since the shallow glide angle of the RASCAL compounded radar problems, but the majority of the Board felt that Sandia should develop the fuze.

The problem was then referred to the Division of Military Application, as noted in Chapter I, and final decision made to assign fuzing responsibility to the Air Force. The problem was turned over to the Bell Aircraft Company, which somewhat reluctantly issued subcontracts to various barometric-switch manufacturers for the development of suitable devices.

replied that the Air Force still desired a RASCAL capability with the XW-5 Warhead, and that Mk 5 flight tests were now scheduled for the period January through September 1956, while missiles configured to carry the XW-27 would not be available until October 1956.[72]

However, further study and negotiation resulted in cancellation of the Mk 5/RASCAL program in March 1956. A quantity of components and hardware to convert Mk 5 Bombs to XW-5-X1/RASCAL warhead installations was retained for a temporary period for possible combat use.[73]

CHAPTER V

MISCELLANEOUS MISSILES

RIGEL

Field Command notified Sandia August 28, 1950, that the Navy was planning to incorporate a Mk 5 Warhead into the RIGEL guided missile.[74] Information regarding this missile was requested from its contractor, the Grumman Aircraft Engineering Corporation, during a missile conference held at Sandia Base September 27-28, 1950. The Navy requested that provisions be made for the RIGEL to carry either the Mk 5, Mk 7 or Mk 8 Warhead.

Field Command pointed out to Sandia, in a letter dated November 29, 1950, that design of the RIGEL contemplated boosted launch from a short-rail launcher. The booster rockets would accelerate the missile from rest to approximately Mach 1.7 in about 4 seconds, after which the boosters would be jettisoned and the ramjet engines would further accelerate the missile to a cruising speed of Mach 2. During the boost phase, the longitudinal acceleration would be as high as 17 g's, and it appeared possible that accelerations of 20 g's might be experienced for short periods of time.[75]

The Mk 5 Warhead could withstand accelerations of 8 to 10 g's, but reduction of RIGEL launch accelerations to this level would require a major program, involving several years of research into composition and burning rates of propellants. Since the prototype warhead for the RIGEL would not be needed until 1954, it was hoped that a rugged implosion-type warhead might be developed by that time, and a request was made that Sandia make preliminary study of a Mk 5 implosion design that could withstand longitudinal accelerations of 20 g's.

A set of detailed missile characteristics was furnished to Sandia April 25, 1951.[76] This described the RIGEL as a supersonic, submarine-to-surface,

bombardment missile with a maximum diameter of 45 inches, a length of over 45 feet, and able to carry a warhead weight of 3000 pounds.

After launch, the missile would climb to a cruising altitude of 50,000 feet and fly to an "area of influence" of guidance stations, where mid-course guidance would be provided. This system was a modified Loran type, using two submerged submarines as control stations. The missile would interrogate the submarines and fly along a hyperbolic path established by these replies. The replies were timed so that the missile path would pass through a target release point. At this point the missile would automatically push over into either a programmed ballistic or homing path to the target. The first tactical missile firing was planned for November 1952, initial firing from a submarine in November 1954, and Fleet evaluation in December 1955.

Little subsequent work was done, however, and, September 30, 1953, the Division of Military Application notified Santa Fe Operations Office that the RIGEL program had been canceled and that requirements for an atomic warhead installation for this missile had been withdrawn.[77]

HERMES

The Sandia Weapons Development Board was notified March 13, 1951, that the Army was developing proximity fuzes for use with the HERMES missile carrying a conventional warhead. It was noted that the military characteristics for these fuzes were similar to those of atomic weapons, except for the higher reliability required in atomic weapons. Inasmuch as this increase in reliability could be achieved by using multiple fuzing, it was suggested that the Board make formal assignment of this project to the Army.[78]

On May 21, 1951, the Division of Military Application sent a teletype to Sandia, stating that the HERMES missile had been deleted from the marriage program, and that the Sandia program should be adjusted accordingly.[79] The

Military Liaison Committee notified the Division of Military Application on June 4, 1951, that the missile had been formally removed from the list of approved weapons projects, but that it had been added to the list of guided-missile test vehicles.[80]

Meetings were held in late 1951, to discuss the possibilities of reinstating the Mk 5 Warhead into the HERMES, so that a missile warhead-compartment design could be produced that would be compatible with Sandia's handling equipment. By May 27, 1952, schedules were being firmed up. Static tests would start April 1953, and flight tests July 1953. The missile operational date would be late 1954, with full production by early 1956. Operational suitability tests of the Mk 5 Warhead in the HERMES missile were planned for mid-1954.[81] General Electric Company, contractor for the HERMES missile, proposed that Sandia enter the project January 1954, by which date the third missile would be available for use.

Sandia was assigned design responsibility for the nose cone, which would have to be pressurized during flight to prevent electrical breakdown of the components. Some difficulty was anticipated with sealing problems, since the ring on which the nose cone was mounted did not lend itself readily to such designs. Sandia suggested, in a letter to Field Command June 9, 1952, that the nose cone be redesigned by the missile contractor, since it was closely associated with the missile airframe design.[82]

Sandia notified the Sandia Field Office of the AEC, June 11, 1952, that conferences with the missile contractor had determined that systems tests could start no earlier than October 1953. Design release would be accomplished by March 1954.[83]

Sandia wrote to Field Command September 25, 1952, stating that nose cones would be furnished for test flights of all HERMES missiles. These would contain inert warheads and Sandia-designed fuzes. It appeared that either a barometrically armed radar fuze or a pure barometric fuze would be used, but it was stated that design responsibility for the fuze had not been formally assigned.

On October 16, 1952, Field Command stated that, due to budget cuts, the HERMES program would be delayed about 6 months.[84] Thus, no current action would be taken on the formation of an Ad Hoc Working Group.[85]

Fiscal funds were still lacking by August 25, 1953.[86] On September 18, 1953, the Military Liaison Committee notified the Division of Military Application that the Army had terminated the development of the HERMES missile as an operational weapon, and that the requirement for an atomic warhead installation for this missile was accordingly withdrawn.[87]

F-101

On April 9, 1953, the Division of Military Application notified Santa Fe Operations Office that the Joint Chiefs of Staff had established a military requirement for development of a streamlined case to enable a supersonic fighter-type aircraft to externally carry the Mk 5 Bomb. Initial application was to be made to F-101 aircraft, and it was considered desirable that the Air Force proceed with the development of the case and the associated non-nuclear components.[88]

A study was made by Wright Air Development Center, after which the Air Force directed McDonnell Aircraft Corporation to develop an externally carried case, named Store 96. This Store was a symmetrical shape 394 inches long and with a maximum diameter of 44 inches. It had three tail fins, with the lower fin retractable to provide ground clearance for loading the weapon and for takeoffs and landings. Gross weight of the shape, including the Mk 5 Warhead and 849 gallons of fuel, was 9240 pounds. The fuel would be expended by the aircraft en route to the target, and, at release, with all fuel expended, the Store would weigh 3776 pounds. The weapon could be released from the carrying aircraft by low-altitude bombing release, M-1 bombing computing system, or by dive bombing, with optical sighting. An ejector mechanism would assist to separate the bomb from the airplane at release.

By fall 1953, the design had progressed to the point where initial test flights could be undertaken by mid-1954 and operational capability could be achieved by January 1956. Early flight tests would be made in B-47 bombers, with 15 drops being made to check out weapon stability and barometric sensing. A subsequent test series would check the fuzing and firing system, and separation under varying conditions.[89]

An XW-5/F-101 Joint Project Group was formed August 1953 to coordinate activities of the Armed Forces Special Weapons Project, the Air Force Special Weapons Center, and Sandia in the shape 96 project.[90] By the July 20, 1954, meeting of the Group, it had been decided to use a radar-timer-contact fuze, and to discard a baro-timer-contact design that had also been considered.[91]

On April 26, 1955, AEC notified Sandia that thermonuclear warheads should be considered for application to the Shape 96. Sandia would provide an appropriate arming and fuzing system.[92] Some thought was given to the application of a Mk 15 Warhead, but this proposal was deleted.[93] In March 1956 the Air Research and Development Command canceled the applications of both the Mk 5 and Mk 27 programs to the F-101, as flight tests had demonstrated fairing problems causing buffeting.[94] Attempts were made to solve these problems; but the program had been delayed to the point that other, and better, weapon combinations became available.[95]

Glossary of Mk 5 Warhead Terms

Air Force Special Weapons Center -- That element of the Air Force Systems Command having to do with compatibility testing of nuclear devices with aircraft. Located at Kirtland Air Force Base, Albuquerque, New Mexico.

Armed Forces Special Weapons Project -- An interdepartment agency formed to handle military functions related to atomic weapons.

Barometric Fuze -- Fuze incorporating a baroswitch. A pressure device actuated by increasing air pressure as the warhead descends in its trajectory.

Capsule -- The nuclear ~~capsule~~ element of an atomic weapon which, when subjected to compression in the implosion process, becomes supercritical and produces a nuclear reaction.

Cartridge -- An assembly, generally containing fuzing and firing system elements, which can be inserted and removed from an atomic weapon in the manner of a cartridge being inserted or removed from the chamber of a rifle.

Contact Fuze -- A fuze that detonates the weapon by contact with the ground or the target.

Department of Defense -- The Armed Forces, i.e., the Army, Navy and Air Force.

Detonators -- Explosive devices which when initiated by the proper signal the same charges of the high explosive sphere. ~~Devices containing bridge wires which, when subjected to an electrical load, burn rapidly and act as a match to apply a flame to various points on the outer surface of the high explosive sphere.~~

Division of Military Application -- An AEC office that functions as liaison between the Military and weapon designers and producers.

Dump -- The point in its trajectory at which a guided missile "dumps" or turns toward the target.

Fat Man Bomb -- The implosion device used during World War II in the attack on Nagasaki. So-called due to its bulging contour.

Field Command -- The local office of the Armed Forces Special Weapons Project, located on Sandia Base, Albuquerque, New Mexico.

Fuze -- A combination of the arming and firing devices of a weapon.

g -- Force equal to one unit gravity.

provided with appropriate lenses charges to implode the explosion

Implosion -- The effect created when a sphere of high explosive is detonated on its exterior surface. The force of the exploding wave is directed largely toward the center of the sphere.

Jato -- Named for Jet-Assisted Take-Off. A jet device initially designed to assist heavily loaded aircraft to take off from short runways. Used as a boosting device in missile launching.

A group composed of the Chiefs of Staff of the

Joint Chiefs of Staff -- ~~An~~ Army-Navy-Air Force ~~group~~ to determine policy and to develop joint strategic objectives of the Armed Forces.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico.

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Mark 27 -- A relatively small and light thermonuclear weapon, developed both as bomb and warhead.

Military Liaison Committee -- A Department of Defense Committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

Nautical Mile -- A naval measurement of length. One nautical mile is equivalent to 6076.1033 feet, or the length of 1 minute of arc (1/21,600) of a great circle of the earth.

Prototype -- An early weapon type, generally hand-produced before a production run.

Proximity Fuze -- A fuze that detonates the weapon as soon as it comes within a certain specified distance of the ground or target.

hollow metal shell which receives

Pit -- The ~~space~~ at the center of an implosion bomb. The nuclear capsule is inserted into this space.

Radar -- Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Sandia Weapons Development Board -- A joint Sandia-Military board at Sandia Base to provide local guidance on weapons design.

Santa Fe Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with the operations of Sandia Corporation.

Special Weapons Development Board -- Change of name for the Sandia Weapons Development Board, effective May 14, 1952.

Subsonic -- Any speed below that of Mach 1.0, which is the speed of sound, or 738 miles per hour at sea level.

Supersonic -- Any speed exceeding that of Mach 1.0.

Telemetry -- The transmission of signals from a moving object.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

X-Unit -- ~~A high-voltage transformer.~~ A device used to provide high voltage to the weapon detonators.

XW-8 -- A gun-type weapon, designed for target penetration.

Z Division -- A division of the Los Alamos Scientific Laboratory, elements of which moved to Sandia Base and became the nucleus of Sandia Laboratory.

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TIMETABLE OF MK 5 WARHEAD EVENTS

1900	Rocketry has beginnings as a science.
1929	Nazis start intensive study of guided missiles.
Early 1946	Rand Project founded. Early rocket-study work.
3-46	Army Air Forces institute work on Project MASTIFF, an experimental missile.
1-10-47	Early proposals for atomic warheads.
4-29-49	Division of Military Application requests views of Military Liaison Committee on missile/atomic warhead work.
1-27-50	Detailed studies of missile/atomic warheads approved.
6-21-50	Sandia Weapons Development Board accepts cognizance of missile/warhead work.
10-1-50	Department 1270 established at Sandia for missile/warhead design.
9-11-51	Military characteristics for XW-5 Warhead issued.
8-53	Mk 5 Mod 0 Warhead design released.
7-54	Mk 5 Mod 0 Warhead enters production.

Mk 5/REGULUS

1-50	Project approved by Secretary of Defense.
1-51	Missile/warhead placed in active design.
9-10-51	XW-5/REGULUS Ad Hoc Working Group meets.
8-18-52	RAM Project initiated.
10-28-52	Flight tests of XW-5/REGULUS started.
9-53	Design release of Mk 5/REGULUS.
4-54	Initial production of Mk 5/REGULUS.

The success of the Germans in developing the V-missiles and the later appearance of the atomic bomb led observers to believe that a quick "marriage" of the two would follow and inaugurate an era of "pushbutton warfare." Such estimates failed to evaluate properly the complexities attendant on the development of each device and the relatively primitive state of each.[2] Lacking were such factors as reliable guidance systems, competent propulsion systems, shock-resistant warheads, and the high-quality, or "clean-room," type of manufacturing facilities yet to be developed. However, early military characteristics for an air-to-ground missile had been proposed by the Army Air Force October 19, 1945, envisioning a warhead 60 inches in diameter, 130 inches long, and 11,000 pounds in weight (in obvious reference to the Fat Man bomb), although missiles capable of carrying a warhead of this size and weight would not be available for several years.

In March 1946 the Army Air Force directed the Air Materiel Command to develop an experimental missile, and this project was given a code name of MASTIFF.[3] At the time, little information regarding MASTIFF was made available to those working on the atomic bomb, but in one of his last actions, December 12, 1946, as head of the Manhattan Engineer District and prior to AEC assumption of control, Brig. Gen. Leslie R. Groves informed the Los Alamos Scientific Laboratory concerning the project, and stated that it envisaged installation of an atomic warhead in an air-to-ground guided missile.

This information was referred to the Z Division on January 10, 1947, with a request that preliminary analysis be made, but that any sizable amount of development work be deferred until later in the year when the work load was expected to taper off.[4] Subsequently, little was done on the project in either AEC or military circles beyond a general study that contemplated use of a plane-launched drone which would glide 300 miles to a target at a speed of 300 miles per hour. However, a drone with this speed was felt to be highly vulnerable to antiaircraft fire, and the existing scarcity of nuclear material, together with the inaccuracy of drone control systems, caused apprehension that an atomic weapon might be used to bomb some unoccupied field. In mid-1947, missile development for the MASTIFF project

Subsequently, separate conferences were held with the three Services and Sandia Base representatives of the Armed Forces Special Weapons Project. These conferences explored the details of weapon-missile relationships, placing emphasis on Mk 5 and Mk 8 Warheads.

The Sandia Weapons Development Board provided a common forum for designer and user of atomic weapons and, in a meeting June 21, 1950, agreed to accept responsibility for coordinating guided-missile and atomic-warhead development. The Board proposed that a strong missile subcommittee be formed, but temporarily deferred appointments to this subcommittee, pending arrival of new officer assignments at Sandia and Kirtland Air Force Bases.[8]

The Division of Military Application had noted, in a letter dated June 14, 1950, that some controversy had arisen over the subject of responsibility for warhead fuzing. Army Ordnance had assumed that the Atomic Energy Commission would handle fuze development, but the AEC felt that the fuze characteristics would be strongly affected by missile operation and environment, and therefore the fuze should be designed by the missile agency.[9]

This subject was discussed in the June 21, 1950, meeting of the Sandia Weapons Development Board. One proposal was that the AEC provide funds for fuze development and retain nominal control of the project, with the work being accomplished by Army Ordnance or missile contractor. The Board in general felt that the missile was simply a carrier, that it replaced the aircraft carrying bombs, and that the fuze was part of warhead development. However, it was recognized that there was no easily defined line of demarcation between warhead and missile (such as between bomb and bomber), and the eventual ruling was that a decision on fuzing design responsibility would be made for each individual missile-warhead project. The Board proposed that AEC budget for fuzing development costs in the immediate future and that these funds be allocated to the military or AEC contractor assigned responsibility for fuze development.

involved, that of ballistic (where the missile was launched upward and then fell into a target) and that of release from a carrier downward onto a target.

The Division of Military Application notified the Military Liaison Committee, January 19, 1951, that increasing requirements for various combinations of missiles and warheads had reached the point where standardization of warhead design was becoming difficult, if not impossible, to achieve. It was felt that the design of the Mk 5 and Mk 7 Warheads had progressed to the point where these warheads could be proposed for marriage with missiles and eliminate any need for alternate warheads.[16]

A nomenclature system having the prefix "XW" to identify warheads under design, similar to the "TX" identification for bombs, was authorized in mid-January 1951. This prefix was followed by the warhead identification (Mark number) and was coupled with the missile designator for complete missile-warhead nomenclature. The "X" stood for experimental, and the "W" for warhead. A typical example was: XW-5/REGULUS.[17]

Detailed design was meanwhile proceeding on the arming system. It was felt that automatic arming should be provided, which would take place only after the missile had crossed into enemy territory, and it had been proposed that the missile guidance system be used to signal this fact. However, there was such a complexity of missiles, with different guidance systems, that this was found to be impracticable. It was possible, however, to provide a system that would sense the initial missile speed, the existence of high-enough thrust for long-enough time, the attainment of sufficient altitude, and the pursuance of the correct direction. All these factors could be gaged by gyroscopes, clocks and acceleration switches, and a system could be devised to permit nuclear insertion only when all these factors had been met or exceeded. Sandia provided such a system for all missile-warhead combinations, with the gyroscope, clock, or switch shorted out when a given missile had no need to measure that particular factor.[18]

Sandia presented a status report on its warhead-missile program February 23, 1951, when it was visited by Kaufman T. Keller, Chairman of the Board of the Chrysler Corporation, who had been appointed Director of the Guided Missiles Office by the Secretary of Defense. Keller noted that he had visited a good many places in his work as Missile Czar, but that he was "not going to worry about a place as obviously competent as this one." High praise indeed for Sandia work in this new field.[19]

Work began in earnest on warhead designs after AEC budgetary decisions were made May 31, 1951. It had become evident that much redesign would be required to strengthen the Mk 4 before it could be used as a warhead, and it was also evident that missiles capable of carrying such a heavy warhead were still some years in the future. Thus it was decided to suspend consideration of either the Mk 4 or Mk 6 weapon for current missile applications.

The question of fuzing responsibility was again raised. The first Ad Hoc Working Group to take action in this area, that for the XW-7/CORPORAL, recommended that Sandia provide an interim fuzing system, with Army Ordnance being responsible for the ultimate fuzing design. This proposal was approved by the Sandia Weapons Development Board June 27, 1951, and similar suggestions for the XW-5/REGULUS and XW-5/MATADOR were made and accepted in September and December 1951. These decisions were based on the fact that Sandia fuzes developed for bomb programs were the only systems capable of meeting time scales and adequately accomplishing the technical job.

Allocation of ultimate fuze design to the Army resulted in a request from that agency for AEC funds to develop an ultimate fuze for the XW-7/CORPORAL.[20] This request was referred to the Board, which decided in January 1952 to reduce the scope of the CORPORAL ultimate fuzing study to that of feasibility investigation.[21]

TRITON missiles. The warhead was not to exceed 44 inches in diameter, 77-1/2 inches in length, and 3000 pounds in weight. (b)(1), (b)(3)

Nonradiating fuzes were felt to be highly desirable, setting of burst height was to be possible just prior to missile launching, and preflight checks were to be of a simple accept or reject type.

The warhead was to be capable of withstanding accelerations of +7 g's and -5.5 g's along the longitudinal axis of the missile, although the RIGEL might require resistance against +20 g's. Accelerations of ±3.5 g's along the lateral axis and ±4 g's along any other axis would also have to be withstood. The warhead was to be able to resist temperatures from -65 to +160°F, and altitudes up to 80,000 feet. Air-launched missile warheads would have to withstand flights in the parent aircraft of up to 15 hours at 40,000 feet; and submarine-launched missiles would have to provide for storage of the warhead in the missile for as long as 75 days.[24]

A variety of interpretations had previously been given to definition of warhead and warhead installation, and were standardized by the Sandia Weapons Development Board December 11, 1951. The warhead was defined as the nuclear pit and capsule, high-explosive sphere, detonators, X-unit, firing switch, nuclear insertion mechanism, and all hardware and cabling pertaining to these items. The warhead installation included the warhead, arming and fuzing system, power supply, and installation hardware. The warhead installation thus might vary for different missiles, even though the same warhead was used.[25]

The XW-5 Warhead would contain a Mk 5 Bomb implosion system, a Mk 5 Firing Set with a fast-firing X-unit and switch for contact bursts, and a new linear nuclear insertion mechanism.[26] Mk 5 nuclear capsules would be

used. This would produce a warhead 44 inches in diameter and 75-1/2 inches in length with a weight of 2550 pounds, excluding power supply, arming and fuzing, and mounting hardware.[27]

The Sandia Weapons Development Board ruled that the warhead installation should not be design released until six successful tests of the warhead in the missile had been made. Missile availability dates were still largely indefinite, but it was felt that at least 9 months would be required between design release and early production.

The Mk 5 Mod 0 Warhead was design released August 1953, and production was achieved July 1954. The warhead incorporated a linear nuclear insertion mechanism, but otherwise was identical with the Mk 5 Bomb less outer case. (b)(1), (b)(3)

A Mk 5 Mod 1 Warhead was proposed for use with the RASCAL missile, incorporating dual-motor nuclear insertion mechanism, but was canceled during design, April 16, 1956.[28]

Investigation was undertaken of both forward extending pressure probes and trailing devices. It was hoped to develop a simple barometric fuze, but tests showed that the pressure pickups did not give reproducible results, and that the missile would have to travel faster than Mach 1.0 to prevent premature fuze operation.[32] A decision was made to use a baro-armed radar fuze, a modification of the fuze design of the Mk 5 Bomb.[33]

In early 1952 the Mk 5/REGULUS was given a higher priority than its Mk 8 counterpart, since there was a limitation in the number of missiles available for test flights.[34] Work was started on a contact fuze for several missiles, and successful completion of this task made it possible to provide the XW-5/REGULUS with two fuzing options; radar air burst with contact-fuze backup, and surface burst by impact crystals.

The Navy had requested that a pure barometric fuze be developed, and this was discussed in the June 27, 1952, meeting of the Ad Hoc Working Group. Sandia reported that this design would require an additional 10 months, and that it was not at all certain that such fuze would have the required accuracy. The Group, after considerable discussion, decided to approve the radar fuze for use in the REGULUS and to continue development of a barometric fuze.

The RAM Program (for REGULUS Assault Missile) was initiated by a letter from the Military Liaison Committee to the Division of Military Application August 18, 1952. This was a project to provide the capability for launching the REGULUS missile from a surface ship, guiding the missile to target, and arming and detonating the warhead by command from carrier-based fighter aircraft.[35]

The program was given a high priority in mid-February 1953, and a small number of Mk 5 Bombs were placed in standby storage April 1953, together with the hardware to convert these bombs to RAM installation, which had been renamed the REGULUS Interim Capability Program. These units were subsequently retired in mid-1954, as normal XW-5/REGULUS components became available.[36]

A new high-speed missile, the REGULUS II, was being developed. This would travel at twice the speed of the original REGULUS, or about Mach 2.0, and this increased velocity would more than double the ability of the missile to penetrate enemy defenses without being shot down. Test vehicles of the new design would be available by the fall of 1955, and a feasibility study was authorized by the Secretary of Defense December 1953.[38] The REGULUS II program was promoted to full-scale development stage in April 1955.[39]

Tests of the pressure-sensing system for the XW-5/RG-X1 showed that excessive lag was involved. This was traced to collapse of rubber tubing in the system, and was corrected by the use of metal tubing. This, however, required additional missile flights, and the design release date was postponed to January 1955.

On August 19, 1954, the Military Liaison Committee proposed that responsibility for REGULUS adaption kits be transferred to the Navy. A meeting was held October 28, 1954, at which it was decided that this transfer would be made July 1, 1955.[40]

(b)(3)

Inflight insertion and command arming were accomplished satisfactorily, although the flight came to an abrupt termination when the warhead was accidentally detonated just short of the target. However, missile and warhead performance were satisfactory throughout the 23-minute flight, which covered 173 miles.[41]

Evaluation flights from submarines were largely successful. Impact tests indicated that the contact crystals generated sufficient voltage to detonate the warhead, and that this detonation occurred prior to warhead deformation. Impacts produced by travel through rain or hail, however, would not cause premature detonation. Thus, the system was given general release.

It had been suggested that the design with the barometric fuze be identified as a Mod change upon entry into stockpile. Action on this suggestion, however, was tabled pending assumption of design control by the Navy. Subsequently, it was decided that the Mk 5 Warhead would be replaced by the Mk 27, and all Sandia activity was suspended on the Mk 5/REGULUS Warhead Installation March 1, 1956.[42]

CHAPTER III

MK 5/MATADOR WARHEAD

The MATADOR was a surface-to-surface, turbojet-powered, transonic missile with a range of about 600 nautical miles. The missile was constructed in the shape of a streamlined fighter plane with an over-all length of 39 feet, maximum diameter of slightly over 4 feet, and swept-back wings. It was launched from a zero-length launcher by a single, solid-propellant rocket, which accelerated the missile until the turbojet engine could attain enough thrust to sustain flight. This rocket booster was pneumatically ejected at time of burnout.

At launch, the missile climbed to an altitude of 40,000 feet, then followed a level trajectory to a "dump point" where it pushed over and dove into the target. Two guidance systems were proposed for use, Shanicle and Marc. Shanicle used four ground stations, which generated guidance beams. The missile received these signals and converted them into azimuth and range guidance. Marc used two trailers that tracked the missile and sent command signals. When the "dive point" was reached with either system, the missile followed a programmed terminal trajectory to the target. MATADOR was designed and built by the Glenn L. Martin Company for the Air Force.

The missile was initially considered for marriage with an XW-5 atomic warhead in early 1950.[43] The MATADOR project was accelerated in late 1950, due to the situation in Korea, and on December 18, 1950, the Joint Chiefs of Staff recommended to the Secretary of Defense that a number of missile projects be approved, among them the MATADOR.[44]

Much of 1951 was taken up with consideration of the solution of general problems relating to the development of atomic warheads for guided missiles, and it was not until October 3, 1951, that an XW-5/MATADOR Ad Hoc Working Group was named by the Guided Missiles Committee and held its first meeting. The Group proposed that both radiating and nonradiating fuzes be considered,

SECRET
RESTRICTED DATA



Figure 4. RACHEL Missile

SECRET
RESTRICTED DATA

CHAPTER IV

MK 5/RASCAL WARHEAD

The RASCAL was an air-to-surface, rocket-powered, supersonic missile with a 90-nautical-mile range. The missile was 32 feet long and 4 feet in diameter, with one set of four fins near the nose and another at the tail. The missile was developed by the Bell Aircraft Company for the Air Force. Its name was formed from the title RAdar SCAnning Link.[61]

After launch from the carrying bomber at an altitude between 30,000 and 40,000 feet, the RASCAL was to climb to an altitude of 60,000 feet, and cruise at Mach 2.5. The missile was given mid-course guidance by the launch aircraft. Terminal guidance during the dive to the target was provided by an inertial system and terminal guidance radar which searched the target area and relayed a video output to the launch aircraft. In this airplane, one operator tracked the target in range while another operator tracked it in azimuth. This information was fed into a computer which relayed guidance commands to the missile.

The program was initially proposed in a letter from the Military Liaison Committee March 16, 1950, which listed several missiles which were to be considered for marriage with nuclear warheads. The August 20, 1950, meeting of the Sandia Weapons Development Board noted that it should be fairly easy to develop a nuclear insertion device for the missile, and that the RASCAL had several features that made it particularly appropriate for use. The missile terminal guidance system contained information concerning height of the missile above target, and could be used as the warhead fuze. The missile would be launched only after the mother plane had penetrated enemy territory, so the warhead could be armed before launch.

replied that the Air Force still desired a RASCAL capability with the XW-5 Warhead, and that Mk 5 flight tests were now scheduled for the period January through September 1956, while missiles configured to carry the XW-27 would not be available until October 1956.[72]

However, further study and negotiation resulted in cancellation of the Mk 5/RASCAL program in March 1956. A quantity of components and hardware to convert Mk 5 Bombs to XW-5-X1/RASCAL warhead installations was retained for a temporary period for possible combat use.[73]

CHAPTER V

MISCELLANEOUS MISSILES

RIGEL

Field Command notified Sandia August 28, 1950, that the Navy was planning to incorporate a Mk 5 Warhead into the RIGEL guided missile.[74] Information regarding this missile was requested from its contractor, the Grumman Aircraft Engineering Corporation, during a missile conference held at Sandia Base September 27-28, 1950. The Navy requested that provisions be made for the RIGEL to carry either the Mk 5, Mk 7 or Mk 8 Warhead.

Field Command pointed out to Sandia, in a letter dated November 29, 1950, that design of the RIGEL contemplated boosted launch from a short-rail launcher. The booster rockets would accelerate the missile from rest to approximately Mach 1.7 in about 4 seconds, after which the boosters would be jettisoned and the ramjet engines would further accelerate the missile to a cruising speed of Mach 2. During the boost phase, the longitudinal acceleration would be as high as 17 g's, and it appeared possible that accelerations of 20 g's might be experienced for short periods of time.[75]

The Mk 5 Warhead could withstand accelerations of 8 to 10 g's, but reduction of RIGEL launch accelerations to this level would require a major program, involving several years of research into composition and burning rates of propellants. Since the prototype warhead for the RIGEL would not be needed until 1954, it was hoped that a rugged implosion-type warhead might be developed by that time, and a request was made that Sandia make preliminary study of a Mk 5 implosion design that could withstand longitudinal accelerations of 20 g's.

A set of detailed missile characteristics was furnished to Sandia April 25, 1951.[76] This described the RIGEL as a supersonic, submarine-to-surface,

bombardment missile with a maximum diameter of 45 inches, a length of over 45 feet, and able to carry a warhead weight of 3000 pounds.

After launch, the missile would climb to a cruising altitude of 50,000 feet and fly to an "area of influence" of guidance stations, where mid-course guidance would be provided. This system was a modified Loran type, using two submerged submarines as control stations. The missile would interrogate the submarines and fly along a hyperbolic path established by these replies. The replies were timed so that the missile path would pass through a target release point. At this point the missile would automatically push over into either a programmed ballistic or homing path to the target. The first tactical missile firing was planned for November 1952, initial firing from a submarine in November 1954, and Fleet evaluation in December 1955.

Little subsequent work was done, however, and, September 30, 1953, the Division of Military Application notified Santa Fe Operations Office that the RIGEL program had been canceled and that requirements for an atomic warhead installation for this missile had been withdrawn.[77]

HERMES

The Sandia Weapons Development Board was notified March 13, 1951, that the Army was developing proximity fuzes for use with the HERMES missile carrying a conventional warhead. It was noted that the military characteristics for these fuzes were similar to those of atomic weapons, except for the higher reliability required in atomic weapons. Inasmuch as this increase in reliability could be achieved by using multiple fuzing, it was suggested that the Board make formal assignment of this project to the Army.[78]

On May 21, 1951, the Division of Military Application sent a teletype to Sandia, stating that the HERMES missile had been delcted from the marriage program, and that the Sandia program should be adjusted accordingly.[79] The

Military Liaison Committee notified the Division of Military Application on June 4, 1951, that the missile had been formally removed from the list of approved weapons projects, but that it had been added to the list of guided-missile test vehicles.[80]

Meetings were held in late 1951, to discuss the possibilities of reinstating the Mk 5 Warhead into the HERMES, so that a missile warhead-compartment design could be produced that would be compatible with Sandia's handling equipment. By May 27, 1952, schedules were being firmed up. Static tests would start April 1953, and flight tests July 1953. The missile operational date would be late 1954, with full production by early 1956. Operational suitability tests of the Mk 5 Warhead in the HERMES missile were planned for mid-1954.[81] General Electric Company, contractor for the HERMES missile, proposed that Sandia enter the project January 1954, by which date the third missile would be available for use.

Sandia was assigned design responsibility for the nose cone, which would have to be pressurized during flight to prevent electrical breakdown of the components. Some difficulty was anticipated with sealing problems, since the ring on which the nose cone was mounted did not lend itself readily to such designs. Sandia suggested, in a letter to Field Command June 9, 1952, that the nose cone be redesigned by the missile contractor, since it was closely associated with the missile airframe design.[82]

Sandia notified the Sandia Field Office of the AEC, June 11, 1952, that conferences with the missile contractor had determined that systems tests could start no earlier than October 1953. Design release would be accomplished by March 1954.[83]

Sandia wrote to Field Command September 25, 1952, stating that nose cones would be furnished for test flights of all HERMES missiles. These would contain inert warheads and Sandia-designed fuzes. It appeared that either a barometrically armed radar fuze or a pure barometric fuze would be used, but it was stated that design responsibility for the fuze had not been formally assigned.

On October 16, 1952, Field Command stated that, due to budget cuts, the HERMES program would be delayed about 6 months.[84] Thus, no current action would be taken on the formation of an Ad Hoc Working Group.[85]

Fiscal funds were still lacking by August 25, 1953.[86] On September 18, 1953, the Military Liaison Committee notified the Division of Military Application that the Army had terminated the development of the HERMES missile as an operational weapon, and that the requirement for an atomic warhead installation for this missile was accordingly withdrawn.[87]

F-101

On April 9, 1953, the Division of Military Application notified Santa Fe Operations Office that the Joint Chiefs of Staff had established a military requirement for development of a streamlined case to enable a supersonic fighter-type aircraft to externally carry the Mk 5 Bomb. Initial application was to be made to F-101 aircraft, and it was considered desirable that the Air Force proceed with the development of the case and the associated non-nuclear components.[88]

A study was made by Wright Air Development Center, after which the Air Force directed McDonnell Aircraft Corporation to develop an externally carried case, named Store 96. This Store was a symmetrical shape 394 inches long and with a maximum diameter of 44 inches. It had three tail fins, with the lower fin retractable to provide ground clearance for loading the weapon and for takeoffs and landings. Gross weight of the shape, including the Mk 5 Warhead and 849 gallons of fuel, was 9240 pounds. The fuel would be expended by the aircraft en route to the target, and, at release, with all fuel expended, the Store would weigh 3776 pounds. The weapon could be released from the carrying aircraft by low-altitude bombing release, M-1 bombing computing system, or by dive bombing, with optical sighting. An ejector mechanism would assist to separate the bomb from the airplane at release.

Glossary of Mk 5 Warhead Terms

Air Force Special Weapons Center — That element of the Air Force Systems Command having to do with compatibility testing of nuclear devices with aircraft. Located at Kirtland Air Force Base, Albuquerque, New Mexico.

Armed Forces Special Weapons Project — An interdepartment agency formed to handle military functions related to atomic weapons.

Barometric Fuze — Fuze incorporating a baroswitch. A pressure device actuated by increasing air pressure as the warhead descends in its trajectory.

Capsule — The nuclear ~~capsule~~ of an atomic weapon which, when subjected to compression in the implosion process, becomes supercritical and produces a nuclear reaction.

Cartridge — An assembly, generally containing fuzing and firing system elements, which can be inserted and removed from an atomic weapon in the manner of a cartridge being inserted or removed from the chamber of a rifle.

Contact Fuze — A fuze that detonates the weapon by contact with the ground or the target.

Department of Defense — The Armed Forces, i.e., the Army, Navy and Air Force.

Detonators — ~~Devices containing bridge wires which, when subjected to an electrical load, burn rapidly and act as a match to apply a flame to various points on the outer surface of the high explosive sphere.~~

Division of Military Application — An AEC office that functions as liaison between the Military and weapon designers and producers.

Dump — The point in its trajectory at which a guided missile "dumps" or turns toward the target.

Fat Man Bomb — The implosion device used during World War II in the attack on Nagasaki. So-called due to its bulging contour.

Field Command — The local office of the Armed Forces Special Weapons Project, located on Sandia Base, Albuquerque, New Mexico.

Fuze — A combination of the arming and firing devices of a weapon.

g — Force equal to one unit gravity.

Implosion — The effect created when a sphere of high explosive is detonated on its exterior surface. The force of the exploding wave is directed largely toward the center of the sphere.

Jato — Named for Jet-Assisted Take-Off. A jet device initially designed to assist heavily loaded aircraft to take off from short runways. Used as a boosting device in missile launching.

Joint Chiefs of Staff — An Army-Navy-Air Force group to determine policy and to develop joint strategic objectives of the Armed Forces.

Kiloton — A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Los Alamos Scientific Laboratory — A nuclear design organization located at Los Alamos, New Mexico.

Mach — A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Mark 27 — A relatively small and light thermonuclear weapon, developed both as bomb and warhead.

Military Liaison Committee — A Department of Defense Committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

Nautical Mile — A naval measurement of length. One nautical mile is equivalent to 6076.1033 feet, or the length of 1 minute of arc (1/21,600) of a great circle of the earth.

(b)(3)

Radar — Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Sandia Weapons Development Board — A joint Sandia-Military board at Sandia Base to provide local guidance on weapons design.

Santa Fe Operations Office — The local office of the Atomic Energy Commission (AEC) concerned with the operations of Sandia Corporation.

Special Weapons Development Board — Change of name for the Sandia Weapons Development Board, effective May 14, 1952.

Subsonic — Any speed below that of Mach 1.0, which is the speed of sound, or 738 miles per hour at sea level.

Supersonic — Any speed exceeding that of Mach 1.0.

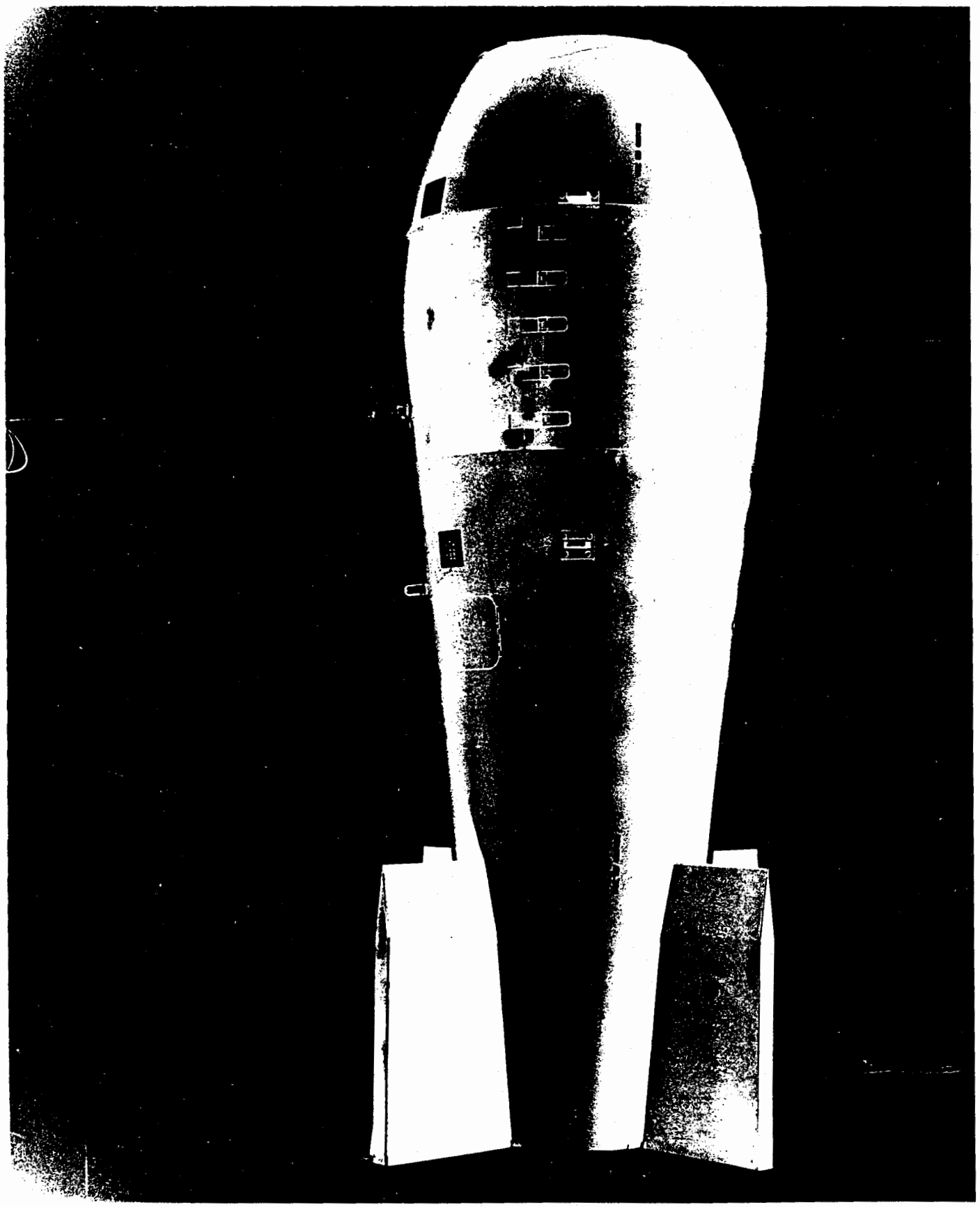
Telemetry — The transmission of signals from a moving object.

Thermonuclear — Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

X-Unit — ~~A high voltage transformer~~ A device used to provide high voltage to the weapon detonators.

XW-8 — A gun-type weapon, designed for target penetration.

Z Division — A division of the Los Alamos Scientific Laboratory, elements of which moved to Sandia Base and became the nucleus of Sandia Laboratory.



Mark 5 Bomb - Exterior View

TIMETABLE OF MK 5 BOMB EVENTS

1946-7	Nuclear studies of small implosion device begun.
10-31-47	Military Liaison Committee requests design of smaller and lighter implosion bomb.
1948	Los Alamos Scientific Laboratory makes detailed nuclear studies of small device.

DoE
b(3)

DoD
b(1)

DoE
b(3)

6-1-51	Mk 5 Mod 0 released for production and stockpiling.
11-52	Mk 5 Mod 1 stockpiled.
6-54	Mk 5 Mod 2 stockpiled.
1-55	Mk 5 Mod 3 stockpiled.

HISTORY OF THE MK 5 BOMB

The feasibility of creating a small implosion bomb was one of the weapon concepts studied by the Los Alamos Scientific Laboratory after the end of World War II. The over-all size of the wartime Fat Man device (which was to be as large as possible) had been established by the dimensions of the B-29 bomb bay and the existing state of implosion theory, and the resulting weapon was a bomb with reasonably high nuclear efficiency, but which was difficult to handle due to its bulk and weight (60-inch diameter; 128-inch length; 10,900-pound weight). Consequently, calculations were made of compressions produced by small-diameter high-explosive spheres, and different arrangements of nuclear material were studied.

This small implosion design was of interest to the Military, and the Military Liaison Committee informed the Atomic Energy Commission October 31, 1947, that current implosion bombs did not lend themselves to wide or flexible employment, and that a weapon both lighter and smaller than the Mk 4 (then in design) would be of considerable military importance.[1] The Atomic Energy Commission, in replying to this letter on December 10, 1947, pledged support of a vigorous program to develop a small bomb.[2]

Meanwhile the Division of Military Application wrote to Santa Fe Operations Office November 25, 1947, noting that any reduction in bomb weight would result in an increased range of the carrying aircraft and pointed out that: "Reduced dimensions might open up an entire new field of flexibility in the employment which could be a decisive influence in the military capability of getting the bombs home in war."

[redacted]

DoD b(1)

During 1948, it became apparent that determination of size, shape and weight for the lighter and smaller weapon required an understanding of military aircraft, delivery plans and problems. A conference was consequently held at Los Alamos September 2 and 3, 1948, which was attended by representatives of the Military, AEC weapon laboratories, and cleared members of the aircraft industry. It was decided that a bomb with a diameter of 40 to 48 inches and weighing between 5000 and 6000 pounds would cause significant improvement in aircraft performance and increase the probability of successful weapon delivery. It was felt that the length of the weapon should be retained at 128 inches.[4]

DoE b(3)

DoD b(3)

DoE b(3)

During the foregoing study period, the project had been known as the Small Weapon Program and was directed by the Los Alamos Committee for Weapon Development. It was subsequently transferred, October 11, 1948, to the W (Weapon Development) Division of Los Alamos with the request that this Division undertake an "experimental, calculational, and fabrication program aimed at the production of a specific model of a complete small weapon for test early in 1951."[6]

The Committee for Weapon Development and the Military Liaison Committee had previously determined that the yield should be [redacted] kilotons; nuclear safing was mandatory; fuzing requirements should be based on the results of a height-of-burst study then in process; and the bomb should be an internally carried, free-fall, air-burst weapon.

DoE b(3)

The work of the W Division almost immediately involved the Sandia Branch of the Los Alamos Scientific Laboratory and, it was suggested that a Steering Committee be established to direct development work on the weapon.[7] This new group initially met November 3, 1948, and the Chairman noted that much confusion had previously arisen due to various terms used to identify a given weapon, and suggested that a standard weapon name as well as a designation for the Steering Committee be established.[8] Mk IV nomenclature had already been assigned, so it was logical to use the next number, Mk V, for this device. The Committee felt, however, that development models of the weapon should be specifically identified, and it was decided to use the letter "X" as a prefix to show the experimental nature of the design. It was also decided to add the letter "T" to indicate--in the phraseology of the Committee's minutes--"the word 'tentative' or 'tiny' (or something)." Thus the weapon became known as TX-V (and, soon thereafter, the TX-5) and the Committee as the TX-5 Steering Committee. The adoption of this system set the pattern for many subsequent atomic devices.[9]

[redacted]

DoE b(3)

DoE b(3)

[redacted] The possibilities of contact or even subsurface burst requirements were briefly considered, but it was felt that the basic design of an implosion weapon made anything but air burst impossible.

DOE b(3)

[redacted]

DOE b(3)

[redacted] Computer time was scheduled, and it was hoped to have compression figures in about 3 months.[10] (Subsequently, due to the pressure of other computer programs, it was decided to interpolate, using other computational results.) The Steering Committee established a schedule calling for preliminary design by January 1, 1950, and complete design July 1, 1950.

DOE b(3)

[redacted]

The contents of a December 10, 1948, letter from the AEC General Advisory Committee were discussed in the January 7, 1949, meeting of the TX-5 Steering Committee. This letter stated that reduction of size and weight of atomic weapons was vitally important to national defense and that the AEC wholeheartedly supported the aims of the Steering Committee in this regard. The Advisory Committee hoped that the new small weapon could be ready for production soon after proof-firing, and suggested that a substantial portion of the implosion stockpile in early 1950 be made up of the new bomb. The program was accordingly accelerated.[12]

Problems of nuclear safing had meanwhile been studied. The Sandia Research and Development Board (later renamed Sandia Weapons Development Board and, still later, Special Weapons Development Board) was a group including representatives from Sandia and the Armed Forces Special Weapons Project, the military organization formed to handle military problems connected with the atomic bomb. The Board held an initial meeting March 2, 1948, and suggested that design attention be paid to the possibility of extracting

Consideration was given to the necessity for duplicate bridge wires in each detonator [redacted] DoE b(3)

[redacted] The use of single bridge wires was then proposed, with two X-units connected in parallel to each bridge wire. This raised the question as to whether one X-unit would fire back through the other, rather than across the bridge wires, and it was eventually decided to provide one highly reliable X-unit and to use single bridge wires.

Initial Sandia mention of the new weapon was made in a progress report of February 18, 1949, wherein it was noted that SLE-7 had been organized as the FM Mk V Division.[18] This Division, in starting design work, was confronted with the general shortage of office and engineering space and facilities at Sandia, caused by the concurrent startup or expansion of other design projects.

Selection of aircraft to carry the TX-5 was discussed in the Steering Committee meeting April 8, 1949. The Air Force program was currently slanted toward use of heavy, long-range bombardment aircraft. Medium-size Navy bombers were still under design, and would not be in production for at least 2 years. Consequently, there was some feeling that current schedules might produce a new bomb before a suitable bomber became available.[19]

As a result of the above meeting, a TX-5 Ad Hoc Panel was appointed by the Military Lisison Committee May 12, 1949.[20] This Panel was composed of representatives of the three Services and, in the course of several meetings and discussions during the summer of 1949, came to feel that the [redacted] DoE b(3)

[redacted] discussed in the July 19, 1949, meeting of the TX-5 Steering Committee. It was agreed that as small a diameter as practicable should be selected, since it would be relatively DoE b(3)

simple to scale upward. A suggestion was made that the bomb be made small enough to fit into a guided missile, but this appeared unduly restrictive. The diameter selected was enough of a departure from previous full-scale detonations to constitute a valid experiment in the laboratory sense, and yet was a size for which some compression computations had been made. [redacted]

DoE b(3)

Throughout the rest of 1949, design studies were made of components such as inflight insertion mechanism, power supplies, and firing sets. Wind-tunnel tests were made of ballistic shapes, and studies made of possible asymmetries which might result from malfunctioning of one or more detonators. [redacted]

DoE b(3)

The general subject of bomb size came in for considerable discussion. Some members of the Steering Committee pointed out that current Rand Corporation studies of nuclear weapons favored use of larger bombs. Other members felt that future emphasis on guided missiles would require small nuclear warheads, and the outcome was a decision to continue work on TX-5 with an eye to eventual stockpile production, but to place more emphasis on larger bombs.

The Military Liaison Committee studied the report of its TX-5 Ad Hoc Panel, and requested the Atomic Energy Commission to delay development of small weapons. The AEC responded with a statement emphasizing the need for small bombs, both to increase flexibility of atomic-weapon usage and to maximize possibility of successful weapon delivery by either aircraft or missiles. A letter to the Military Liaison Committee on January 3, 1950, stated that the General Advisory Committee of the AEC was in favor of developing small or tactical atomic devices and concluded that.

"The TX-5 project is one of the weapon developments in which the interest of the Atomic Energy Commission reflects a general concern that within the next few years the problem of successful delivery of atomic weapons may come to overshadow the problem of increasing the destructive potential of the weapons themselves. The Commission recognizes the primary responsibility of the using forces to set forth desired technical characteristics of weapons, as these characteristics bear on the delivery problem. The Commission remains anxious, however, that its best technical effort be contributed to a solution of this problem in all of its variants which impinge in the area of the Commission's responsibility. The Commission will therefore continue to keep you fully informed of prospective reductions in weapon size and weight, hoping that full advantage will be taken of these forecasts to ease the problems of development of future carriers, a field in which the development cycle is of course substantially longer than the usual cycle of development of the associated weapons."[22]

The Military Liaison Committee wrote to the Division of Military Application February 9, 1950, noting their belief that large-implosion-bomb performance could be considerably improved through use of nuclear design improvements produced by the TX-5 work, and stating that the smaller bomb should be reserved for use in guided missiles.

DoD b(1)

The Division of Military Application stated, in a reply dated March 30, 1950, that the TX-5 nuclear design improvements might obviate any need for larger bombs, but agreed that higher priority would be assigned to use of the TX-5 with future guided missiles.[24]

The ballistic problem was by now well on the way to solution. Extensive experimentation had been undertaken, and a series of 28 different configurations of nose and tail designs had been tested in wind tunnels. A flat nose and large double-wedge fin tail were selected,[28] and the long slender shape of the TX-5 aided materially in producing an aerodynamically satisfactory product.

Deliberate oscillations were created in full-scale drops by use of rocket "kickers" attached to the bomb case, but these oscillations were quickly damped out by the inherent stability of the ballistic shape. A small fin tab was added to impart a slight rotation and improve the trajectory.[29] Weapons were released from various bombers under different conditions. Those dropped from a B-47 at high speeds and low altitudes experienced violent oscillations caused by the air flow around the bomb bay, which imparted a negative pitching moment to the bomb,[30] and this bomber was eventually eliminated as a TX-5 carrier.[31]

[redacted] DOE b(3)

The Fission Weapon Committee of Los Alamos Scientific Laboratory met December 11, 1950, and proposed that experimental small-scale air bursts be detonated in Nevada. [redacted]

DoE b(3)

[redacted]

Mk 5 production was now proceeding at full speed, but encountering procurement difficulties; and a Sandia letter to the Division of Military

Application April 26, 1951, noted that even defense-order classifications could not assure deliveries of needed material and parts when competing with the country's defense buildup. It was concluded that: "It is only by almost superhuman efforts and the full cooperation from all quarters that we can, at this time, even think of delivering the Mk 5 Mod 0 weapon together with its ancillary equipment as early as February of 1952."[32]

The Mk 5 Mod 0 was released for production June 1, 1951.[33] The TX-5 Steering Committee (which had been renamed the TX-N Steering Committee on December 15, 1950, to reflect its broader interest in all implosion-type weapons) approved the design release and then severed its Mk 5 interests by concluding: "It is believed that the Committee's executive functions in the development of the Mk 5 Mod 0 are herewith completed except as specific changes in the weapon are brought to the Committee for approval."[34]

The Mk 5, as released to production June 1, 1951, was a free-fall, air-burst, implosion-type, radar-and-baro-fuzed strategic bomb. Its outside diameter was 43-3/4 inches; length, 128-1/2 inches; and weight, 3300 pounds.

DoE b1

Due to the accelerated schedule, environmental tests were conducted on components, rather than complete weapons. Sandia completed its first assembly and inspection of a Mk 5 Mod 0 in March 1952, and released the weapon for operational service testing and military training. Stockpile entry started soon afterward.

During production of the early Mod 0 Bombs, some design changes were made that were incorporated in the early units. An investigation had been made of methods for quickly attaching and detaching the ~~rear case~~ center band segments (for purposes of weapon servicing), and it was decided to use trunk latches.[35]

The Armed Forces Special Weapons Project reported the existence of sneak circuits in the weapon junction box, and it was found that when the low-burst cable was used, there was a possibility that motor timer clutches could be

unlatched during final assembly or postloading tests.[36] This could cause detonation if the weapon were subsequently released below the altitude at which the arming baro had been set; as a result, expedited investigation and action were undertaken. The low-burst cables were temporarily withdrawn, testers modified, and the low-burst capability restored in April 1952.

The Mk 5 Mod 0 Bomb was discussed in the August 6, 1952, meeting of the Special Weapons Development Board. It was noted that contact resistance of the baroswitches increased with age, but that this could be corrected by cleaning the contacts with solvent, changing the insulating material to eliminate an outgassing problem, and using gold alloy contacts. The inflight insertion mechanism had a tendency to overshoot and cause excessive wear, and a slipping clutch was added to correct this difficulty. The Board accepted the weapon for stockpiling, since corrective action was being taken on these items.[37]

The Mk 5 Mod 1 Bomb resulted from an Armed Forces Special Weapons Project request that cables to supply external power to heaters for batteries and radars be provided to maintain these items at operating temperature in cold weather. Stockpile production of the Mk 5 Mod 1 started November 1952.[38]

On October 13, 1953, Sandia suggested that the inflight insertion mechanism of the Mk 5 Bombs be reworked to incorporate all design changes that had been proposed in this apparatus. At the same time it was suggested that the cartridge mounting be altered to allow a bomb-to-warhead conversion capability, and this proposal was accepted. Design release was effected November 1953 and the revised weapon stockpiled in June 1954 as the Mk 5 Mod 2 Bomb.[39]

A considerable change to the Mk 5 Bomb was made in the Mod 3, which incorporated a new fuze. General dissatisfaction with the complexities of a radar fuze had caused Sandia to examine other methods, and an intensive study of this subject was instituted in mid-1951.[40] The simplest system would have been a pure barometric fuze, but this design had large inherent inaccuracies.[41] An impact fuze offered many advantages, including that of

destruction of the bomb in the event the regular fuze failed, and much effort was expended on this device. This required the use of a fast-firing X-unit, and suitable design work was instituted.[42]

By the fall of 1952, a four-option fuzing system was being studied for Mk 5 application. This system included baro primary, radar primary, timer primary, and contact. Contact backup would be provided for the three air-burst options. The fuzing option would be selected during weapon assembly, through an access port in the skin of the bomb, by insertion of the proper plug in the top of the junction box.

A report on the above proposal was made to the Special Weapons Development Board September 10, 1952. Some members of the Board felt that remote selection of the fuzing option should be possible from the bomber while the weapon was being carried to the target, and other Board members requested that Sandia study the possibility of providing a fifth option, that of a baro-armed radar fuze.[43]

A proposal for a modification of the Mk 5 with the above five fuzing options, together with a suitable fast-firing X-unit, was forwarded to the Division of Military Application on October 22, 1952, and subsequently referred to the Military Liaison Committee.[44] The Committee, in their review of the proposal, requested deletion of the radar fuzing option and asked that inflight selectability be provided for the baro, timer and contact options. This requirement was discussed at the December 10, 1952, meeting of the Special Weapons Development Board, and it was agreed that the new fuze could be designed by May 1953.[45]

In the meantime, the concurrent development of many different fuzes for various weapons had generated concern, within both Sandia and the Armed Forces Special Weapons Project. By January 15, 1953, five such fuzes were currently under design for the Mks 5, 6, 7, 12 and 13. These fuzes required 30 different pieces of support equipment, and it was felt that this proliferation of gear would complicate training, operations, and

logistics. Inasmuch as the Mks 5, 6 and 13 were strategic weapons designed for high-altitude bombing, it was suggested that the fuzes for these weapons be merged in a single design, called Fuze A. This could be a barocontact fuze with a safe-separation timer. The Mks 7 and 12 Bombs could be provided with a fuze for attack of tactical targets, and this would be called Fuze B, with primary fuzing a choice of radar, timer or contact.[46]

The subject was discussed in the January 21 and February 18, 1953, meetings of the Special Weapons Development Board, with a joint presentation being made by Field Command and Sandia Corporation.[47] It was pointed out that Fuze B was essentially the Mk 7 Mod 1 Fuze scheduled to enter stockpile in June 1953, and that this fuze would be available sooner than Fuze A. It was then decided that Fuze B would initially be used in the Mk 5 with a radar-fuzed air burst, pending availability of Fuze A, which would provide a contact capability.[48] The interim use of Fuze B was accepted by the Military Liaison Committee with some misgivings, as it was felt that the ultimate objective for the Mk 5 Bomb was elimination of radars in favor of baro fuzing.[49]

New bomb production requirements through mid-1955 were subsequently approved by the Secretary for Defense and transmitted to the Atomic Energy Commission May 15, 1953.[50] No new production of the Mk 5 Bomb was authorized, and concentration of effort on Fuze A for the Mk 5 was requested. Work on application of Fuze B to the Mk 5 was accordingly dropped, and a Mod change to the Mk 5 with Fuze A application was approved. This became the Mk 5 Mod 3 and was a baro-armed, baro-fuzed system, with contact backup. Mod 3 was design-released February 1954 and War Reserve entry was effected [redacted] The dimensions were the same as previous Mods, but the weight was reduced to 3025 pounds. This was the final modification on the Mk 5 Bomb design.

DOE b(3

GLOSSARY OF MK 5 TERMS

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions relating to atomic weapons. Activated by memo order from the Secretaries of War and Navy, dated January 29, 1947. The Air Force was represented after passage of the National Security Act of July 29, 1947.

B-29 -- A heavy-bombardment-type, propeller-driven, four-engine aircraft.

Ballistics -- The science which studies the laws governing the motion of projectiles or of bombs dropped from aircraft.

Bridge Wires -- ~~High~~ Low-resistance wires which, ~~when~~ subjected to a high voltage pulse from the weapon X-unit, ~~fuse and burst into flame, thus providing a means of detonating the high explosive sphere.~~ in the detonator (which see) these ignite the explosive elements at the detonator.

Capsule -- The nuclear ~~capsule~~ element of the weapon which, when subjected to compression in the implosion process, becomes supercritical and produces a nuclear reaction.

Committee on Atomic Energy -- Established by the Joint Research and Development Board (which see) in the summer of 1946.

Detonators -- ~~These contain the bridge wires (which see) which, when subjected to a sudden electrical load, burn rapidly and act as a match to apply a flame to various points on the outer surface of the high explosive sphere (which see).~~ Explosive devices which when initiated (see Bridge Wires) by the X-unit ignite the lens charges of the high-explosive sphere (which see).

Division of Military Application -- An AEC office which functions as liaison between the Military and the weapons designers and producers. By provision of the Atomic Energy Act, the Director of this Division is an active member of the Armed Forces.

Fat Man -- Code name for the implosion weapon dropped on Nagasaki, Japan, during World War II. So named for its short, fat silhouette in contradistinction to the early gun-type weapon, which was called the Thin Man (later the Little Boy). The term was extended to include the general designs of early implosion weapons.

General Advisory Committee of the AEC -- The group established by the Atomic Energy Act to provide policy direction for the Atomic Energy Commission.

[redacted] DOE b(3)

High-Explosive Sphere -- The ball of high explosive that surrounds the nuclear capsule and produces the implosion effect when detonated.

pit and is designed to

Implosion-Type Bomb -- A weapon based on the principle discovered by Professor Charles E. Munroe, Washington, D. C. Written up in Scribner's Magazine and the American Journal of Science in 1888, and in Popular Science Monthly in 1900. Rediscovered by Egon Neumann of Germany, who took out German and English patents in 1910-11. The Munroe principle noted that an increased explosive effect was created when an unconfined cylinder of high explosive was hollowed out. In 1920 the Journal of the Society of Chemical Industry (London) stated that "no practical use has apparently been made of this discovery." Suggested by S. H. Neddermeyer at Los Alamos as a means for producing the extremely high pressures required on the capsule of an atomic bomb. Not much attention was paid to the suggestion until it received the backing of John von Neumann and George Kistiakowsky. The same principle was used in the Pacific area in World War II as a means for blasting the occupants of Japanese pill boxes, and for increasing the penetrating effect of shells and warheads.

Joint Research and Development Board -- A replacement for the wartime office of Scientific Research and Development. Established June 6, 1946, by Secretaries of War and Navy to carry on research and development work for new military weapons and equipment.

Kiloton Yield -- A means of measuring the effect of a nuclear explosion by comparing it with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the effect of 1000 tons of high explosive.

Los Alamos Scientific Laboratory -- Founded as the Los Alamos Laboratory in early 1943 as part of the Manhattan Engineer District to undertake weaponization efforts on nuclear devices.

Military Liaison Committee -- A committee established by the Atomic Energy Act of 1946 to advise and consult, on behalf of the Department of Defense, with the AEC on all atomic-energy matters relating to military applications of atomic weapons. Chairman can be any active or retired officer of the Armed Forces. Includes representative or representatives from each department of the Armed Forces.

DoE
b13)

Rand -- Named for Research and Development. A corporation established by the Air Force in early 1946 to study future systems design.

Sandia Research and Development Board -- A joint Sandia Laboratory-Military board formed March 2, 1948, at Sandia Base to provide local guidance on weapons design.

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Sandia
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HISTORY OF THE MK 6 BOMB (U)

(Including the TX/XW-13, Mk 18 and TX-20)

SC-M-67-726

Redacted Version



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Weapon Systems

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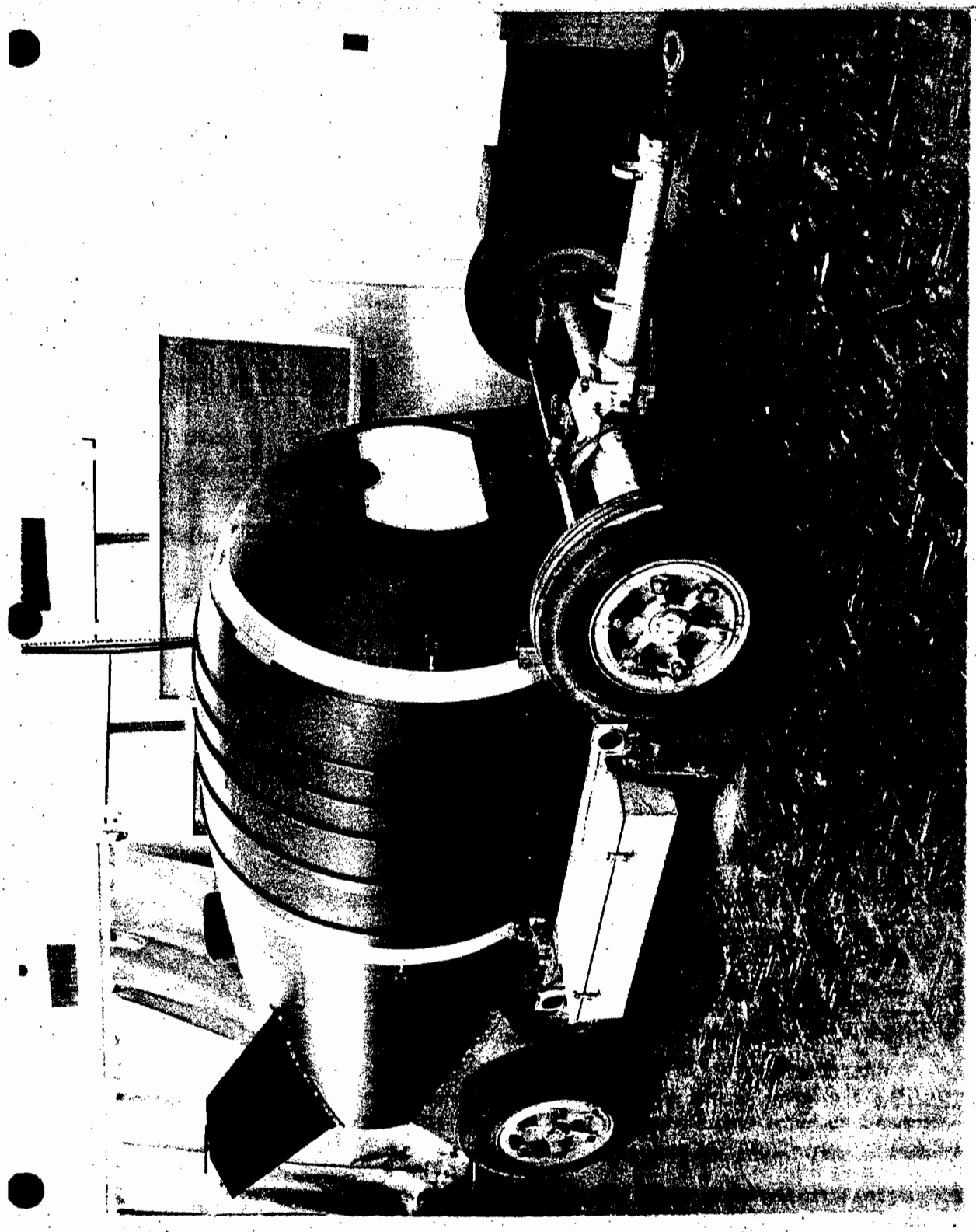
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Mk 6 Bomb on Trailer

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Other design improvements were also being considered. (b)(1), (b)(3)

The scheduling subcommittee of the Sandia Research and Development Board met July 6, 1949 and suggested that a proposed design-release date of February 1950 was overly optimistic and that the production design for the Abee radar could probably not be achieved until mid-1950, thus resulting in availability by the fall of the year. In addition, the ballistics of the lightweight case were proving troublesome, and further wind-tunnel tests and range drops were required. It was recommended that a production date of October 1, 1950 be established for the lightweight case and the new fuzing system.[3]

The schedule was further extended in a letter from the subcommittee to the Board, July 29, 1949, wherein it was proposed that the lightweight case be design-released in May 1950 and stockpiled by February 1, 1951; and that the new fuze be design-released July 1, 1950 and stockpiled by February 1, 1951.[4]

The lightweight case was discussed in the December 21, 1949 meeting of the Sandia Research and Development Board. It was noted that either the riveted or welded design would be selected in the next 3 months, and that the decision would be based on comparative weight, cost, and delivery factors. Consideration was, however, being given to authorizing simultaneous tooling for both types of cases, to save a few months in early production.[5]

The Armed Forces Special Weapons Project notified Sandia January 9, 1950 that improvements to the Mk 4 Bomb were accorded a high priority in the National Military Establishment. It was suggested that perhaps some weight might be ared from the high-explosive sphere case. (b)(1), (b)(3)

radars. (b)(3)

Height-of-burst settings would be adjustable in six steps before weapon assembly, and any one of the six settings could be selected by remote control from the strike aircraft before release. The ranges of these six steps would overlap each other.[16]

Some attention had previously been paid to the possibility of providing inflight insertion. Currently, it was necessary to manually extract two heavy blocks of high explosive, insert the nuclear capsule, replace the high explosive, and button up the assembly. This was tedious and time-consuming, and required that the strike aircraft fly at fairly low altitudes (and thereby at a high rate of fuel consumption) during the insertion process, as the aircraft bomb bays were not pressurized.

The Los Alamos Scientific Laboratory had notified the Division of Military Application that a suitable inflight insertion system could be developed by early 1949.[17] The Division had replied, July 14, 1948, that the Military would gain in safety and logistics if both insertion and extraction in flight could be provided. It was requested that these changes be incorporated as soon as possible.[18]

Los Alamos stated that nuclear efficiency could be improved by better timing of nuclear initiation and that this could be accomplished by use of an external neutron source. (b)(3)

Although this was highly desirable, the Board felt that it would be criticized if production of the Mk 6 was delayed, and suggested that this design revision be held in abeyance.[20]

to arm radars and might be used as primary fuzes if wider burst-height tolerances could be accepted. An improved pressure pickup system was being designed, and such fuzing systems as time of fall, time of flight, flight distance, contact, and pyrotechnic were all being investigated.[27]

The Division of Military Application notified Sandia Field Office, July 30, 1951, that about 20 percent of production Abee's currently being tested by the Air Force Special Weapons Center were failing due to various causes. It was noted that the Department of Defense had concluded that the Abee was not suitable and that baroswitches would have to be used to fire the Mk 6 Bomb.[28]

The problem was referred to Sandia, which replied, July 31, 1951, that recent Air Force experiments on the operation of the Abee motor timer had been conducted. This operation required that the radars be jammed, and the test was completed satisfactorily. Sandia had been informed that this test had been interpreted to mean that the bomb was extremely vulnerable to jamming. It was pointed out, too, that 4-N bombs had been used. Sandia felt that the Abee, as it existed, represented a distinct improvement over the Archie from both operational and reliability standpoints.[29]

Meanwhile the Mk 6 Mod 0 Bomb, which had been design-released May 15, 1951, achieved early production in July 1951.[30] The bomb was subsequently stockpiled, but not accepted for operational use by the Military.

Field Command notified Sandia August 1, 1951, that use of the Mk 4 baroswitch fuzing system, which was scheduled for use in the Mk 6, required an extremely complicated and arduous process. Theoretically, this system was accurate when precisely used but, under the most carefully controlled field conditions, this accuracy was halved. It was urged that an improved system be provided for the Mk 6 Bomb.[31]

The need for early introduction of this modified baroswitch sensing system was discussed in the August 8, 1951 meeting of the Sandia Weapons Development Board.

in accordance with current procedures.[33] To make matters worse, when these two units were again examined upon return from the test (this mission was aborted due to weather), they both failed to pass the standard assembly-type retest. This resulted in examination of a larger number of stockpiled Abee's, using stockpile testers and revised Sandia procedures. Results indicated that about half of these Abee's would fail to pass the test, and Sandia investigations confirmed these findings.[34]

The Sandia Weapons Development Board met September 26, 1951, and continued its appraisal of the Abee radar. It was pointed out that inconsistent results from tests conducted on the same radar at different locations were being reported, and it was suggested that the various pieces of test equipment be compared. It was noted that Abee drop tests had been conducted, and that some radar failures had been reported, but that no dud bombs had resulted. It was felt that, in the event of national emergency, the baroswitches could be used as primary fuzes, but the Military members of the Board stated that this expedient was unacceptable for other than the high-burst option of the Mk 6.

Sandia assigned an overriding priority to the problem, and formed a task group of the most highly qualified Sandia and contractor personnel to investigate all phases of the problem. This group was to issue a formal report of its findings by November 1, 1951.[35] The program was named the GF (for Grouped Forces, code-named Greenfruit) Task Group. The GF task was to conduct a complete evaluation of the Abee, recommend measures to correct existing deficiencies, and implement the necessary corrective measures.[36]

Early investigation by the GF Group discovered that a delay in the transmitter/receiver keep-alive circuit allowed a large transmitted signal breakthrough for the first 200 transmitted pulses and that this caused excessive crystal burnout. This was corrected by a minor wiring change in the unit which provided advance arming of the keep-alive electrode.

The transmitter tube was found to have a slow leak which was traced to a defective ceramic cathode seal and was replaced by an improved arch glass design.[37] The lack of correlation between production-line tests of the Abee and subsequent testing in the field, involved the use of different testing devices which contributed to the problem, and action was taken to revise these tester designs.

It was found that the transmitter/receiver tube was subject to frequent breakage, aggravated by temperature cycling of the tubes in their mounts. Detailed examination showed that high stresses were created and the tube mountings were redesigned. Failure of the ballast tubes was traced to faulty mechanical support of the tube filament. A rigid system of inspection was instituted and tube redesign was started.

Unstable ranging and relay chatter was reported which caused reduced ranging accuracy. A circuit change was made, providing parasitic suppressors to the range deck.[38] The final GF evaluation report, issued in late 1951, recommended that the revised Abee be released to stockpile. Acceptable quality had been achieved, together with good fuzing accuracy at attitude angles up to 28 degrees from the vertical.[39]

Sandia presented Report SC2319(TR), Engineering Evaluation of the Design of the Mk 6 Mod 0 Weapon, to the April 16, 1952 meeting of the Sandia Weapons Development Board. The Board felt that no formal action was necessary. It was pointed out that the Mk 6 Mod 0 would soon cease to exist, as parts were already being procured for the Mk 6 Mod 2 Bomb.[40]

The report was published August 15, 1952. The Mk 6 Mod 0 Bomb was 61 inches in diameter, 128 inches long, and weighed 8500 pounds. It was suspended by a single lug from the internal bomb bays of the B-29, B-36, B-47, B-50, B-52, AJ, A2J and A3D aircraft. (b)(1), (b)(3)

The manual insertion mechanism was the same as that used in the Mk 4 Bomb.

The Mk 6 Mod 0 had two interchangeable, lightweight, aluminum-alloy ballistic cases, one of welded and the other of riveted construction. The bomb was provided with improved barometric pressure sensing and dynamic stability by spoiler bands placed around the central portion of the ballistic case. The Abee radar fuze incorporated a remotely controlled range-setting feature plus circuit refinements that made the bomb more resistant to enemy countermeasures. (b)(1), (b)(3)

Mk 6 Mod 1 Bomb

The Mk 6 Mod 0 was the start of a development effort which was to continue for several years. Technological advances were breaking through on all fronts, both nuclear and nonnuclear, and including the carriers of the bomb. One of

the early changes provided optional use of the Albert radar as an alternate to the Abee radar.

The Albert radar had been started into development, and it had been hoped that units would be available by July 1950. However, the device proved difficult to design and fabricate, and its operational details were not firmed up until mid-1951, when it emerged as a device using different radiated frequencies than the Abee and providing higher transmitted power. (b)(1), (b)(3)

Use of the Albert required a different bomb antenna, and a new nose plate was developed for use with either Abee or Albert. This nose plate incorporated horn-type antennas for the Albert, while a discone antenna was used with the Abee.

Sandia notified the Albert development contractor that a GF-type program should be established to evaluate radar quality prior to production and to provide any steps necessary to achieve a fully satisfactory unit for military use. Thus a program called 3-E (for MC-3 Evaluation) was established in late 1951.[42]

The Albert was designed-released in February 1952 and assembly of units was started. It had been hoped that the 3-E Group could issue a formal report by September 1952, but discrepancies were revealed by the investigation. These problems concerned sensitivity, compatibility, vacuum-tube difficulties, and some mechanical troubles. (b)(1), (b)(3)

It had been discovered that full ranging capability within 10 seconds after application of inverter power was not guaranteed, even with preconditioning.[43]

weapon development was recognized. The Navy was prepared to accept the improved manual inflight insertion system.[47]

Thus, incorporation of the change into stockpile was urged, and schedules were established calling for first delivery in January 1952.[48] (b)(3)

For ease in assembly, the horn antennas were installed on the sphere case rather than on the nose plate as in the previous models, and this eliminated the need for connecting the antenna cables during reassembly of the nose plate after nuclear insertion. The Mk 6 Mod 2 Bomb entered stockpile in January 1952.

Report SC2484(TR), Engineering Evaluation of the Mk 6 Mod 3 Bomb, was dated November 17, 1952, but the report also covered the Mod 2. (b)(3)

Mk 6 Mod 3 Bomb

Drop tests of the Mk 6 Mod 2 configuration brought unexpected results. It was found that the radars were firing prematurely, as soon as they were armed by the baroswitches. When weapons were tested in the laboratory, the same thing happened, and investigation disclosed that the radars were "ringing" off the nose cavity of the bomb itself.

It was found that a quarter-inch clearance between the horn antenna and the nose plate of the bomb permitted radio leakage into the cavity between the nose plate and the rest of the bomb. The microwave signal reflected back and forth within this cavity, and then leaked back into the antenna and fired the radar relays.[50]

There were several possible solutions, such as adding absorbent material to the bomb nose or making the nose of plastic material, but the simplest one was to revert to the original configuration by installing the antennas on the nose plate rather than the sphere case. This meant that the antenna cables had to be disconnected for removal of the nose plate and reconnected in flight after nuclear insertion, but this was not considered to be a serious problem and the change was quickly made.[51]

The altered weapon became the Mk 6 Mod 3, which entered stockpile in July 1952.[52] By November of that year, all Mk 6's had been converted to the Mod 3 configuration.

Mk 6 Mod 4 Bomb

This change added a warmup cable. This cable permitted application of 28-volt direct current from an external power source to operate the heaters in the radars and battery cases. It was found that after the weapon had been stored at low temperatures, preheating of these components was necessary to ensure that they would perform properly during checkout tests. After the bomb had been loaded into the strike aircraft, the heaters could be operated through the aircraft pullout cable, using aircraft power. The Mk 6 Mod 4 entered stockpile in November 1952.[53]

Mk 6 Mod 5 Bomb

The Mod 5 incorporated a baroswitch fuze. The Military had for some time advocated replacement of the radars with an all-barometric fuzing system.[54] Their reasons were based not only on the difficulties which had been experienced with

The design also used nickel-cadmium batteries or Mk 2 Power Supply. These batteries replaced a lead-acid design and provided greatly improved operational readiness, since they could be charged in less time and be stored in the charged condition for longer periods. The Mk 6 Mod 5 Bomb entered stockpile in May 1953.

Mk 6 Mod 6 Bomb

The broad objectives of the Mod 6 were to provide contact fuzing and a Mach-insensitive barometric sensing system. This latter system was one which the Military had been requesting for some time.[60] It would provide the correct atmospheric pressure to the baroswitches regardless of the rate of fall of the weapon. Corrections to baroswitch settings were required to compensate for the varying effect of air flow past baroswitch ports at different Mach numbers. Making this correction was troublesome as it involved use of complicated tables incorporating the latest meteorological data, estimating the speed of weapon fall at the altitude at which the baroswitches were to close, and accurately controlling the speed and altitude of the strike aircraft at the time of drop. These problems were discussed at the August 8, 1951 meeting of the Sandia Weapons Development Board, and a formal recommendation was made that development emphasis be continued on a Mach-insensitive design.[32]

The emphasis was applied, but solutions to the problem were found to be quite elusive.[61] Early experiments with drag cones and trailing probes showed some promise. These devices placed the pressure pickup far enough behind the falling bomb to be relatively free of the effect of air flowing past it.

The drag cone showed especially good statistical reliability when the pressure orifices were located at the end of an 18-foot length of flexible hose attached to the bomb tail plate. This proved to be a difficult mechanical installation, however, as the buffeting effect of the air exerted forces on the hose which exceeded the breaking strength of the material, even when stainless-steel hose was tested. Deployment of the device as the bomb fell away from the carrying

Sandia presented Report SC3271(TR), Design Description and Status Report of the Station 124 Pressure Sensing System for the TX-6-X4 Weapon, to the March 31, 1954 meeting of the Special Weapons Development Board. This report described the pressure-sensing system, discussed its capabilities, and summarized the test results. It appeared possible to use a single pressure offset when determining the baroswitch setting, and accept some degradation for those few burst heights (about 2 percent) which would be made at speeds higher than Mach 0.9.[68]

Sandia presented Report SC2540(TR), Engineering Evaluation of the Mk 6 Mod 6 Bomb with Mk 13 Mod 0 Fuze, to the January 12, 1955 meeting of the Special Weapons Development Board. Basic changes included the Mach-insensitive pressure-sensing system and a contact fuze. Contact-fuze tests had included 75-millimeter gun firings to simulate a spike impact, and sled tests to measure sensitivity of the system to rain impact. The Mk 6 Mod 6 entered stockpile in January 1955, and all previous modifications were converted to this design.

Stability of the bomb was satisfactory, except for drops made from B-47 aircraft at low altitudes and high speeds. In these cases the weapon pitched considerably upon release, due to the aerodynamics of the airplane and the bomb. This particular delivery required that bombing-table corrections be made to achieve the desired ballistic accuracy. All components and systems operated satisfactorily during fuzing and firing drop tests.[69]

The bomb diameter was 61 inches, its length 128 inches, and its weight 8170 pounds. (b)(1), (b)(3)

Prior to takeoff, aircraft power was supplied to timer and battery heaters and trigger-circuit filaments. (b)(1), (b)(3)

The safing switch was placed to the arm position.

At bomb release, the pullout switches closed, starting the safe-separation timer and the inverters, and switching the trigger-circuit filaments from aircraft power to internal battery power. At the end of the preset safe-separation time, battery power was provided to the arming relay, which could not operate until the arming baroswitch closed and furnished a path to ground. (b)(1), (b)(3)

Operation of the arm relay then connected the inverter output to the firing-set charging circuits. The firing set completed its charge in about 0.5 second. Three seconds after safe-separation time, another switch in the safe-separation timer closed, completing the fuzing-baroswitch ground circuit, and the weapon was now ready for air-burst detonation.

If the fuzing baroswitch had been set for air burst, it closed at the predetermined altitude, forming a negative pulse which was applied to the trigger-circuit cathodes, firing both thyratrons. The output pulse of the trigger circuit fired both gaps, discharging the main bank condenser energy into the detonator bridge wires, with resultant weapon detonation. If the air-burst fuze failed, detonation occurred at impact.

If the fuzing baroswitch had been set for contact detonation, or if the air-burst fuze failed, impact of the weapon with the target resulted in detonation. The impact caused the crystals to generate a voltage which was applied to both thyratron grids, and the resultant firing of either thyratron initiated the firing sequence.[70]

(b)(3)

The Board met December 11, 1951 and accepted the proposed design.[60] Since the weapon was now no longer interchangeable with other Mk 6 Bombs--a different capsule being required--it was designated the Mk 18.

Only pit and capsule were affected, so most of the development work was carried out by Los Alamos. (b)(3)

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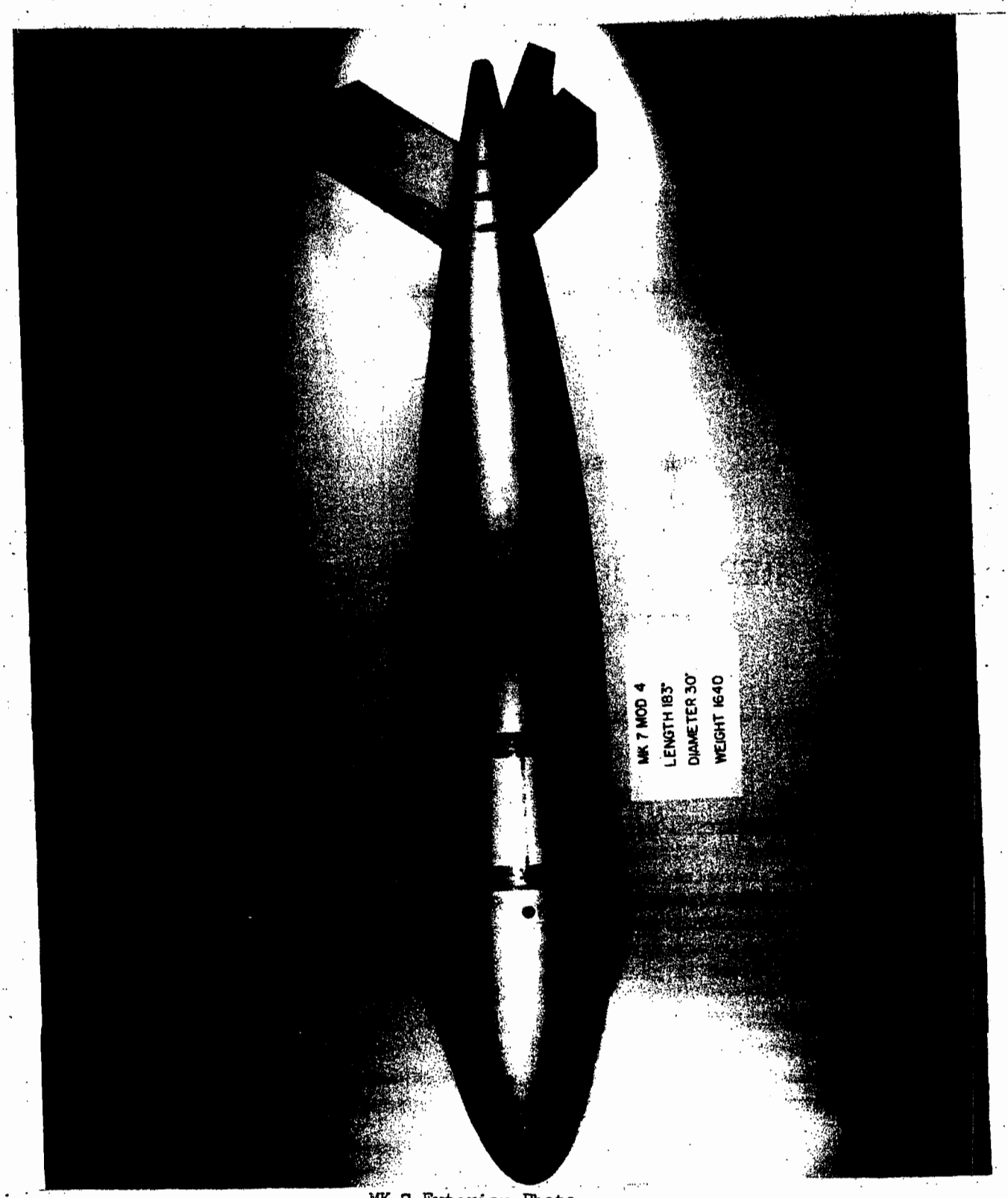
implosion system. However, upon cancellation of the TX-13 in August 1954, the TX-20 program was similarly deleted.

Retirement

With the development of thermonuclear weapons, as well as fission devices of more advanced design, the Mk 6 became obsolete. Removal from stockpile started in 1957 and by July 1962 all Mk 6 units had been retired.

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MK 7 Exterior Photo

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History of the Mk 7 Weapon

The Mk 7 weapon had its beginning in studies made by Group W-4 of the Los Alamos Scientific Laboratory in late 1949 and early 1950. Results of these researches were presented to the May 26, 1950, meeting of the TX-5 Steering Committee by W-4, who noted that the Group was interested in the development of small-diameter bombs for tactical military use.

(b)(3), (b)(1)

A weight of 1900 pounds (compared to 3300 for the Mk 5) was predicted, and a maximum outer bomb diameter of 32 inches.[1]

Detail studies were then started. While these were in progress, the conflict in Korea deepened and resulted in a July 11, 1950, teletype

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from the Division of Military Application which stated:

(b)(3)

Submission of your plan is requested in part or in whole as it is received.[2]

(b)(3)

A TX-5 Steering Committee meeting was held July 17, 1950, followed by a joint meeting August 2, 1950, with the Sandia Weapons Development Board.[4]

(b)(3)

(b)(3) The streamlined shape of the bomb suggested the practicality of external carriage, but this required a complicated nuclear insertion system and made it difficult to retain the nuclear components in the event the bomb had to be jettisoned. Due to the radical change in shape from previous atomic bombs, the ballistics problem required attention, both from the standpoint of external carriage and the release trajectory of the bomb. Aircraft compatibility would entail a major effort, as a variety of tactical airplanes were being designed and produced.[7] It had been proposed that the external case be developed by an aircraft company, and Sandia had already conferred with several West Coast manufacturers. Of these, Douglas Aircraft Company appeared a logical choice, with both space and cleared personnel available, and a contract was subsequently awarded.[8]

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Inflight insertion problems required study.[9] The purpose of inflight insertion was to prevent nuclear detonation from occurring during take-off or landing, reduce nuclear contamination in the event of accident, and allow salvage of nuclear material. Sandia prepared both forward and rear insertion proposals.

(b)(3)

This second type resulted in a considerable shift of the bomb center of gravity during insertion, and the initial decision was to use the forward insertion design. Later, it was decided to place the relatively heavy cartridge at the forward face of the sphere assembly and a horizontally operating insertion mechanism aft of the sphere. Controls were installed in the cockpit of the carrying aircraft, so that insertion or retraction of the capsule could be remotely accomplished in flight.

It was felt that the fuzing system might require attention, but not until information was received from the Military concerning the method of bomb combat use. The firing system would be similar to that used in the TX-5. It was proposed that the bomb length be about six times the diameter and it was predicted that this shape would attain a speed of Mach 1.2 to 1.5 during the bomb drop.

(b)(3)

Closer estimation of the weight placed this figure at 1680 pounds.

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An August 9, 1950, memorandum from the Military Liaison Committee to the Division of Military Application stated that the Joint Chiefs of Staff had established a requirement for air-burst atomic bombs sufficiently light in weight and small in cross section to be carried by high-speed tactical planes.

(b)(3)

The weapon was to be used by fighter or light bombardment aircraft in attacking tactical targets, with the bomb normally being carried externally.

(b)(3)

The bomb was not to exceed 2000 pounds in weight nor 33 inches in diameter and was to have a configuration which would reduce aerodynamic drag to a minimum. Exterior ballistics should allow reproducible trajectories, and the bomb was to be aerodynamically stable. The fuzing system was to permit freedom to select alternate targets at varying altitudes while en route, be relatively nonsusceptible to enemy countermeasures, and allow both air burst and an approximately zero height of burst. However, this last requirement was not to delay the early availability of the bomb.

The bomb was to have a means of nuclear safing, such as remotely controlled inflight insertion and extraction, require only simple adjustment or monitoring, and be capable of release at subsonic and supersonic speeds. It was to be designed for ease of assembly in forward-base areas or on board ship, and be capable of storage for periods up to 6 months in these locations. The bomb was to be able to withstand stresses created by carriage on fighter-aircraft wing pylons and bomb racks. Normal operation was to be possible under icing conditions and throughout a temperature range from -65°F to +165°F.[12]

(b)(3)

Two types of bomb suspension were considered, a three-hook rack with one lug forward and two lugs aft, and a two-lug design.[13]

A 14-percent scale model was built and tested at the Cooperative Wind Tunnel at the California Institute of Technology. A drag coefficient of less than 0.042 was reported, as compared to 0.54 for the Mk 4. This indicated the general superiority of the long, thin shape, and it was proposed that the bomb length be increased to 192 inches, the maximum possible without the bomb striking the runway on takeoff or landing. To provide more ground clearance, it was decided to use three fins instead of four, and to make the lower fin retractable. Later, the bomb was shortened to about its originally proposed length, or 183 inches, to permit carriage of the weapon on certain Navy aircraft.[14]

(b)(3)

Douglas Aircraft Company reported development of a family of shapes that appeared satisfactory from below sonic speed up to Mach 1.2. Meetings with Air Force representatives underscored the emerging need for tactical nuclear weapons, and orders were issued for early modification of a group of Tactical Air Command F-84E airplanes to carry the TX-7.

Completion of wind-tunnel model tests at speeds up to Mach 1.2 demonstrated that the shapes possessed adequate stability, and full-scale drops were started. The first such drop at the Salton Sea Test Base resulted in the bomb's going into gyrations of 45 degrees and shedding its tail assembly, while another drop produced severe pitching action. Immediate and intensive investigation was undertaken, and it was found that fin misalignment caused circular wobbling of the tail, and that this instability was augmented when the misalignment was enough to cause

the bomb body to rotate at the same rate as its natural pitching frequency. The problem was solved by holding the fin alignment to ±1/2 degree, and by stiffening the fixed fins by base angles and the retractable fin by guide rollers.[16] Spin tabs were added to generate a roll rate which would always be greater than the natural pitch frequency.

Terminal velocity during full-scale drops was found to be about Mach 1.0, in an unstable or buffeting region, and it was felt necessary to reduce this speed. A drogue-chute design was proposed that incorporated six small fins to which were attached risers of a 36-inch-diameter parachute. Experimentation, however, showed that operation was strongly affected by relatively minor changes in wind, air density, airspeed, and release altitude.

Dive brakes were tested and proved satisfactory. The first such design had an area of 87 square inches, causing too much drag, and the area was reduced to 70 square inches. The length of the fin, initially 26 inches, was increased to 30-1/2 inches for improved stability. This was found to provide insufficient clearance with carrying aircraft, and the length was eventually established at 29 inches.

The foregoing studies were interwoven with the problem of providing an accurate barometric pressure-sensing system for bomb altitude determination. Nose probes were tested, but could not be made long enough to reach unaffected pressure regions ahead of the falling bomb. Trailing probes were subjected to excessive whipping in flight and to freezing of the mechanism. Eventually, the problem was alleviated by the reduced speed of fall resulting from the use of dive brakes. Studies conducted at the Salton Sea Test Base resulted in locating the pressure ports on the bomb case 125 inches aft of the nose.

Flight tests were conducted on the F-84 aircraft at Muroc Dry Lake, California. The TX-7 store was installed on the right wing pylon and a

(b)(3)

This order was amended September 4, 1951, to require production-quality fuzes. Sandia noted that this second program would continue to divert engineering effort, already severely affected by the 7N work, and delay regular Mk 7 production.[28] Sandia was subsequently relieved of work in connection with this second 7N program,[29] but later was requested to inspect and certify some of the 7N components used in the program.[30]

(b)(3)

Sandia pointed out that regular Mk 7 Bombs would be available soon after this date, and this third program was canceled.[31]

The Mk 7 Mod 1 Bomb resulted from a request from the Armed Forces Special Weapons Project that external power be supplied to battery and radar heaters to create proper operating temperatures in cold weather.[32] Stockpile production of this modification started November 1952.

It was felt that the Mk 7 Nose, which formed a radome for the radars, might ice up during external carriage of the bomb. Several methods were studied, including use of a pulsating rubber boot or deicing fluid. Tests showed that a neoprene-coated radome would do the job and at the same time reduce rain erosion damage, and this change was adopted. The carriage of the Mk 7 on many types of aircraft resulted in a requirement for different fin positions, and the design was accordingly amended so

Fuze B was subsequently designed with a timer that could be used to arm the radars (providing safe-separation time) or as a primary fuze by itself. Radar air burst was retained and a contact fuze added which could be used as cleanup or as a primary fuze. An externally accessible remote-setting device permitted preflight selection of safe-separation times coupled with radar ranges.

Tests had shown that boat-tail fins produced increased stability with little or no increase in drag, and this fin design was adopted.[37] Other methods of retarding the speed of bomb drop had been studied, such as parachutes or rotochutes (freely rotating vanes), but these latter designs did not prove entirely satisfactory from the standpoint of bombing accuracy and effectiveness of retardation.

The Mk 7 Mod 3 Bomb entered production June 1953 with the new fuze design and improved ballistic characteristics. The fins were made nonretractable, but could be removed for storage. A visual port was provided in the body of the bomb so that the position of the safety switch (which isolated the battery from the bomb circuits) could be checked. In previous bomb modifications, this check had been made from the cockpit of the carrying aircraft, using a special tester. Weight was reduced slightly, to 1620 pounds.

(b)(1), (b)(3)

This change was incorporated in the Mk 7 Mod 4 Bomb, which also provided a universal warhead that could be used for both bombs and missiles, and which possessed a quick-disconnect radome. The Mod 4 was design-released in March and stockpiled December 1954

(b)(1), (b)(3)

It was found that ejector forces exerted by the Aero 7A Bomb Rack created shock loads which affected timers and radars. Shock-absorption pads were installed to protect the radars, and new shock mounts were designed for the timers. These changes were released October 1956 and the resulting units were stockpiled June 1957 as the Mk 7 Mod 5 Bomb.

(b)(1), (b)(3)

Sandia suggested, February 15, 1960, that additional safing be provided for Mk 7 Bombs being maintained in alert status. Charging of the X-unit would be prevented until the weapon had experienced a normal trajectory. Sandia was requested to provide such design January 25, 1961, and it was suggested that components being produced for the Mk 43 Bomb be used for this purpose.

Wind-tunnel tests of the design gave satisfactory results, but flyaround tests resulted in erratic operation on one type of aircraft. The pressure-switch setting was slightly altered, and the use of a higher spoiler in front of the pressure-switch port produced good results. The change entered production in July 1961 as the Mk 7 Mod 7 Bomb.

Permissive Arming Link devices were released for use in the Mods 5 and 7 Bombs, with production being initiated in February 1963. The Mk 7 Mod 5 became the Mk 7 Mod 8, and the Mk 7 Mod 7 became the Mk 7 Mod 9.

Glossary of Mk 7 Bomb Terms

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions related to atomic weapons.

Ballistics -- The science governing motion of projectiles or bombs dropped from aircraft.

Barometric Fuzing -- Use of a pressure switch actuated by increasing air pressure as the weapon falls in its trajectory to institute weapon fuzing.

Buffeting -- Excessive vibration of a falling bomb caused by weapon instability. Also vibration of a bomb carried externally on aircraft.

Buster-Jangle -- Tests of atomic devices at the Nevada Test Site. Series of seven shots, starting October 22 and ending November 29, 1951.

Capsule -- The nuclear ~~assembly~~ element of an atomic weapon which, when subjected to compression in the implosion process, becomes supercritical and produces a nuclear reaction.

Capsule Retention -- A method of retaining the nuclear capsule while allowing jettisoning of the weapon; of prime importance in the early days of nuclear weaponry, due to scarcity of nuclear material.

Cartridge -- An assembly, generally containing fuzing and firing system elements, which can be inserted and removed from an atomic weapon in the manner of a cartridge being inserted or removed from the chamber of a rifle.

Compatibility Tests -- Tests to prove whether or not the weapon can be easily installed, tested and released from its specified carriers.

Contact Fuze -- A fuze that detonates the weapon by contact with the ground or the target.

Core -- See Capsule.

Detonators -- ~~Devices containing bridge wires which, when subjected to an electrical current, burn rapidly and act as a match to apply a flame to various points on the outer surface of the high explosive~~ explosive devices which when initiated by the current, ignite the lens charge of the high explosive sphere.

Dive Brakes -- ~~Projecting~~ plates, generally at the tail of a weapon, which, when released, slow its fall through the air. Purpose is to reduce the rate of fall (velocity) to well below the speed of Mach 1.0, which was a highly unstable speed region for the early bombs.

Mk 7/ALIAS BETTY

4/16/51	Joints Chiefs of Staff request adaption of atomic warhead for underwater detonation.
10/9/51	Naval Ordnance Laboratory reports feasibility of project.
2/6/52	Military Liaison Committee reports that Joint Chiefs of Staff have established a requirement for development of an atomic bomb capable of inflicting lethal damage to submerged high-speed submarines.
4/14/52	Division of Military Application approves division of responsibilities for project.
6/11/52	Ad Hoc Committee meets and selects XW-7 Warhead.
11/12/52	Military Liaison Committee approves military characteristics for project.
2/54	Production authorization issued.
7/29/54	Mk 7/ALIAS BETTY Warhead installation design released.
6/55	Mk 7/ALIAS BETTY achieves production.

Mk 7/BOAR

2/1/51	Military Liaison Committee states that Bureau of Ordnance will develop an air-launched free-flight rocket capable of carrying an atomic weapon.
6/6/52	Initial meeting of project Steering Committee. Decision made to start active development, using either Mk 7 or Mk 12 Warheads.
7/22/52	Ad Hoc Committee meets and favors Mk 7 Warhead.
10/21/52	Military Liaison Committee establishes military requirements.
11/54	Mk 7/BOAR Warhead installation design released.
10/24/56	Final Development Report issued. No production authorized.

The Mk 7 Mod 0 Warhead was released for production May 1952, and first appeared in stockpile August 1954, as a result of site conversion of bombs to warheads.

(b)(3), (b)(1)

contact bursts were produced by a barium-titanate fuze.

The design was suitable for use with the CORPORAL missile, and also with the HONEST JOHN, which had been added to the list. Its use with certain missiles involved increased g-loadings produced by high accelerations, and it was felt necessary to provide a dual-motor nuclear insertion mechanism. The bomb had a flange, which was removed when the bomb was converted to a warhead. A new forward shape was proposed that would be applicable to the BOAR project and the Mk 7 Bomb, together with a new fuze that reduced the number of radars and incorporated a new barometric-switch design.

All the above modifications were included in a single program which, however, was disapproved by the Special Weapons Development Board.[9] A universal design was subsequently incorporated in the Mk 7 Mod 1 Warhead which was design-released November 1953, and which appeared in stockpile March 1955 as a result of site conversion of bombs to warheads. This design provided a warhead that was fully interchangeable between bombs and missiles.[10] A Mk 7 Mod 2 Warhead with dual-motor insertion mechanism was design-released July 1955, and achieved production October 1956 for use in the NIKE-B and BOAR weapons. This warhead could not be converted to bomb use. The Mk 7 Mod 3 warhead was provided with a permissive arming link, was design-released July 1963, and achieved production in August.

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May 1967

RS 3434/7
AEC ATOMIC WEAPON DATA
Sigma 3, 7
L-7

HISTORY OF GUN-TYPE BOMBS AND WARHEADS (W)

Mks 8, 10 and 11 (U) Title unclassified per susan stinchcomb 4/18/2002

SC-M-67-658

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Mk 8 Exterior View

THE TX-8 BOMB

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(b)(1), (b)(3)

LENGTH—116 IN
DIAMETER—14.5 IN.
WEIGHT—3150 LBS

Mk 8 Cross Section

12/8/50	TX-G Steering Committee appointed and holds initial meeting.
1/26/51	
	(b)(3)
3/15/51	
Early 1951	Externally carried TX-8 Bomb assigned nomenclature of TX-8 Prime.
10/51	TX-8 Prime program divided into two parts: TX-8-X1 (to cover carriage at subsonic speeds) and TX-8-X2 (a program to reduce drag in high-speed carriage).
11/51	Mk 8 Mod 0 achieves production.
1/52	Mk 8 Mod 0 enters stockpile.
4/1/52	
	(b)(3)
9/53	Mk 8 Bomb with Mk 8 Mod 1 Fuze (TX-8-X2) enters stockpile.
11/55	Mk 8 Mod 3 Bomb enters stockpile.
5/57	Mk 8 Bombs retired as Mk 11 enters stockpile.

Mk 8 Warhead

3/50	Gun-type warheads considered for missile application.
9/13/50	Santa Fe Operations Office requests that penetrating warheads be applied to guided missiles.
2/14/51	Santa Fe Operations Office authorizes design of XW-8/REGULUS.
1/18/52	XW-5/REGULUS program assigned priority over XW-8/REGULUS.
8/21/52	Field Command forwards proposed military characteristics for XW-8/REGULUS to Sandia.
9/24/53	Successful XW-8/REGULUS system test held.

8/54 Design of XW-8/REGULUS completed.

5/20/55 Program activity suspended.

TX-10 Weapon

5/6/48 Sandia Research and Development Board assigns priorities to weapon design projects.

1/21/49 Division of Military Application requests Bureau of Ordnance to study possible adaptation of Mk 8 as a light air-burst weapon.

4/22/49 Military Liaison Committee requests that study be restricted to a preliminary investigation.

3/8/50 Guided-missile symposium at Sandia Base proposes use of a light-weight gun-type device as a missile warhead.

7/6/50 Military Liaison Committee releases formal requirement for an air-burst, gun-type warhead.

8/9/50 Military Liaison Committee establishes formal requirement for a lightweight air-turst bomb.

8/17/50 Division of Military Application forwards characteristics for lightweight air-burst bombs.

9/6/50 Bureau of Ordnance, in reply to January 21, 1949 request of the Division of Military Application, offers to adapt the Mk 8 as a lightweight air-burst bomb.

10/3/50 Division of Military Application notifies Bureau of Ordnance that Sandia will develop the lightweight air-burst bomb.

10/18/50 Sandia Weapons Development Board discusses bomb and warhead applications. Santa Fe Operations Office subsequently authorizes deletion of warhead requirement. Bomb officially designated the TX-10.

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4/1/55 Mk 11 design released.

1/1/56 Early production units of Mk 11 (Mk 91 Mod 0) become available.

7/1/56 Mk 91 Mod 0 enters stockpile.

8/56

(b)(3)

History of Gun-Type Bombs and Warheads

Mk 8 Bomb

The gun method of assembling nuclear material, used in the wartime Little Boy design, was the first atomic weapon system to be devised, predating the establishment of the Los Alamos Laboratory. The method was nuclearly inefficient and was largely ignored for a time after the end of World War II, while interest centered on implosion techniques.

(b)(1), (b)(3)

At this time, the Los Alamos Scientific Laboratory was fully occupied in the above-mentioned study of improvements in implosion devices, and suggested that the task of developing a water-penetrating weapon (which probably would use gun techniques) could best be accomplished by a military group. No immediate action was taken on this suggestion, but the subject was briefly examined by the Z Division of Los Alamos in late 1946 and early 1947.

(b)(1), (b)(3)

The topic was subsequently discussed in a meeting of the Weapons Subcommittee of the AEC General Advisory Committee, and a decision made May 15, 1947 that consideration of a penetrating weapon be postponed.[4]

Meanwhile, however, the Military Liaison Committee had been discussing the general subject of subsurface atomic weapons. At the instigation of the Navy member, Rear Admiral William S. Parsons (who had armed the wartime gun-type Little Boy for

its historic drop on Hiroshima), Section ReM of the Navy's Bureau of Ordnance, prepared preliminary sketches of a penetrating gun device.

At about the same time, other groups were considering the same subject. The Joint Research and Development Board had established a Committee on Atomic Energy, and the subject of penetrating weapons was discussed in the October 2, 1947 meeting of this Committee. It was urged that serious consideration be given to the development of a gun-type device suitable for penetration use. Since the AEC weapon laboratories were already fully occupied with other high-priority work, the Committee recommended that the facilities of the Bureau of Ordnance be used.[5]

The Division of Military Application had also been considering the advisability of invoking the assistance of the military services in the development of penetrating weapons. Los Alamos had noted that gun systems were inherently inefficient, and expressed an opinion that the weapons laboratories should continue to concentrate on design of implosion devices.[6] Thus the Military Liaison Committee was requested to assign mechanical design of a gun-type penetration weapon to the Bureau of Ordnance.[7]

These several requests, all in the same vein, were presented for consideration to the Military Liaison Committee which, April 9, 1948, requested the Atomic Energy Commission to undertake development of a penetrating-type weapon, using the facilities of the Bureau of Ordnance.[8] This request was formally presented to the Bureau April 27, 1948, and accepted.[9] A code name of "Minnie" was initially assigned to the project, but was later found to have been used for a Bureau of Ships propulsion project and, in mid-July 1948, the name was changed to "LC" (a follow-on term to "LB," for the Little Boy), and which came to be commonly written as "Elsie."[10] That the Elsie program was considered a matter of some interest to the Military was indicated in a May 6, 1948 meeting of the Sandia Research and Development Board in which the project was assigned top priority, second only to the schedule for getting the Mk 4 Bomb into full-scale production.

The Bureau of Ordnance issued detailed work assignments. The Naval Ordnance Laboratory would be responsible for developing suitable pyrotechnic delay fuzes.

The Naval Ordnance Test Station would study external ballistics and design the tail. The Naval Powder Factory would investigate powder development. The Naval Ordnance Plant would handle much of the manufacturing and testing program, and when this location was subsequently closed, the work would be transferred to the Naval Proving Grounds and the Naval Gun Factory. Section ReM of the Bureau of Ordnance would provide overall design controls, including the task of guaranteeing survival of the nuclear assembly under impact conditions.

The development program would proceed in three overlapping phases. Feasibility and preliminary design studies would outline the most promising general design characteristics of the weapon, and these were scheduled for completion January 1, 1949. The second phase, covering experimental development and testing of prototype weapon design, would be completed a year later. The third phase, manufacture of prototype weapons, would be finished in another year, or January 1, 1951.

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The studies advanced rapidly and, by September 3, 1948, the Bureau of Ordnance could report that the design appeared feasible and that a weapon could probably be devised that would function satisfactorily after impact on water, and possibly after impact on hard surfaces which the weapon might encounter beneath the surface of the water.[11] It was initially felt that the fuze should be actuated at impact and have a delay of 1 to 2 minutes before bomb detonation, but it was later decided that a more reliable bomb would be created if the fuze action were initiated at time of release of the bomb from the carrying aircraft.

The diameter of the bomb would be about 14 inches and the weight would be about 3000 pounds, as compared to 28 inches and 8900 pounds for the Little Boy. These reductions were due to the more compact nuclear assembly and a decrease in the thickness of the bomb case. The shape would be roughly cylindrical, with a flat nose for good penetration characteristics, and the bomb would attain a maximum impact velocity of 1500 feet per second. The minimum release altitude would be 500 feet, to give the bomb enough time during its fall to assume proper entry attitude, and there would be no restriction on maximum release altitude. It was felt that three separate and independent fuzes should be used, to provide adequate relisbility. A meeting was held October 25 and 26, 1948, with Los Alamos assuming the task of developing impact-resistant initiators.[12]

An extensive series of tests was performed. The first group included 174 half-scale bombs of 6.25-inch diameter. These were fabricated in 49 different configurations, and were impacted against targets of steel and concrete at different angles, striking velocities, and missile temperatures ranging from -65°F to +165°F.

(b)(3)

Following the above, some 38 full-scale impact tests were conducted, to confirm the half-scale results. Interior ballistic tests were performed, to check the burning rate of various propellants and the behavior of the missile in the gun barrel. As fuze components became available, they were subjected to the shock produced by firing from a 14.25-inch-diameter railway gun.

Two series of wind-tunnel tests were held, one at the University of Minnesota to obtain aerodynamic coefficients of various tail configurations, and the other at the California Institute of Technology Cooperative Wind Tunnel to evaluate aerodynamic characteristics of five basic designs.

directive was issued August 30, 1950, accompanied by a request that the facilities of the Bureau of Ordnance be used to the fullest extent possible.[17] At this time, the Elsie was assigned nomenclature of TX-8.[18]

An intensive study had been undertaken of changes required to allow external carriage of the TX-8. There were several reasons why these changes were necessary. For one, the fuze system had been designed to operate under protected bomb-bay conditions. For another, the shape of the TX-8, with its blunt nose, caused excessive drag, especially at high speeds.

(b)(3)

It was obvious that this would require considerable study, and it was suggested that the Bureau of Ordnance establish a parallel program for the development of a Mk II Elsie suitable for either internal or external suspension, while work continued on an internally carried TX-8.[19]

The Bureau made a survey and reported that the existing shape of the TX-8 was adequate for subsonic external carriage if some minor changes were made to the tail design,[20] and the shape could be carried in the space available under the centerline of the F4U, AD and A2D airplanes. It was noted that development of a shape for external carriage at supersonic velocities would require additional study and development, and this effort would be of interest in connection with a recent proposal that an XW-8 Warhead be fitted to a guided missile. Subsequently, October 3, 1950, the Division of Military Application authorized development of an externally carried TX-8 with subsonic aircraft and development of a new bomb (the TX-11) for high-speed external carriage.[21]

Meanwhile, the Armed Forces Special Weapons Project had been drawing up a paper specifying the desired military and technical characteristics of penetrating-type weapons.

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This paper was circulated for comment to Sandia and Los Alamos as well as the Military, and was subjected to a critical review.[23] The formal issue of the characteristics on November 10, 1950, however, retained the release speed requirement and noted that the bomb should function reliably when released at any altitude up to 50,000 feet and survive impacts on water, reinforced concrete, and--hopefully--thin steel plate.

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The November 22, 1950 meeting of the Sandia Weapons Development Board reviewed the overall gun-type weapons program, which now included the TX-9, TX-10, and TX-11, in addition to the TX-8. It was noted that the TX-8 was composed of three main parts: The nose, the tail, and the clamping ring which joined them. The bomb diameter had been fixed at 14.5 inches, its length at 116 inches, and its weight at 3260 pounds. The nose was a heavy forging with a blunt shape for water and ground entry, and contained the internal gun barrel, tamper, and projectile.

(b)(3)

A saddle on the external top of the bomb case contained switches and electrical connections to operate the primers.[25]

Sandia had proposed that an interlaboratory gun-type weapon coordination committee be established, similar in scope and authority to the TX-5 Steering Committee. Action was taken on this suggestion in late 1950, and the first meeting of this Gun Committee, with representation from Los Alamos and Sandia, was held December 8, 1950.[26] At this time, the TX-5 Steering Committee was renamed the TX-N Steering Committee to reflect its interest in all implosion weapons, and the new Gun Committee came to be known as the TX-G Steering Committee.

The first meeting of the TX-G Committee heard a report from Los Alamos concerning progress on design of an initiator for the TX-8. The initial design had been based on the device used in the Little Boy, and was then modified as design weaknesses were uncovered by the testing program. Some idea of the problems encountered were shown by the increasing impact requirements as the design progressed. The initial

assumption had been that the highest shock encountered in ground impact would be 7500 g's. This figure had progressively increased during design and was now 100,000 to 300,000 g's.

(b)(3)

Studies were meanwhile in progress on systems for nuclear safing.

(b)(3)

In early 1951 it was decided to identify the adaptation of the TX-8 for external carriage at subsonic speeds as the TX-8' (or TX-8 Prime) program. Plans were made to make only minor changes to the TX-8 and provide early, but only partial, satisfaction of the requirements for an externally carried TX-8. It was felt that, if this program could not be accomplished within a short time, it should be canceled in favor of the TX-11 Bomb, then being designed for external carriage on high-speed aircraft.

At this time, the AD4 and the F4U5 were the only carriers specified for the TX-8'. The AD4 was selected as the test aircraft, and Sandia issued a contract through the Bureau of Aeronautics to Douglas Aircraft Company to modify this aircraft for TX-8 carriage. Douglas designed a nose cap to reduce drag and help protect the TX-8' fuzing elements.

In late October 1951, the TX-8' program was divided into two parts; the TX-8-X1 and TX-8-X2. The X1 was the basic TX-8' program; the X2 was to provide a cleaner aerodynamic design and reduce the drag caused by the saddle. Inasmuch as 20 drops had already been made with the TX-8-X1, its compatibility and reliability were felt to have been proven, and attention was concentrated on the TX-8-X2 design.[33]

The T-28 saddle functions were replaced by a small box located in the aircraft fuselage. This allowed the use of a standard two-hook bomb rack and increased the clearance between the externally carried bomb and the ground. Fairings were installed over the side fuzes to reduce drag. Fuze tapes used for safing were pulled through the nose fairing to protect them from the windstream. A quick disconnect was installed, to permit the weapon to be dropped with tapes in place, thus leaving barriers in the path between the primer and the propellant, and preventing the fuzes from firing the main propellant charge.

This new device was called the T-31, and a subcontract was issued for its development. Due to the subsequent failure of the subcontractor to achieve a satisfactory T-31, Sandia produced a design having the T-31 located inside the bomb pylon, thus making it possible to detach the arming tapes from the pylon after bomb release, and prevent aircraft damage caused by whipping of the tapes in the slipstream. This work was undertaken November 5, 1951, and satisfactory hardware was being produced 10 days later.

The Mk 8 Mod 0 weapon was initially produced in November 1951 and was stockpiled in January 1952.

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The Military Liaison Committee, in a letter dated October 20, 1952, requested that the bomb be designed to withstand storage for 6-month periods under occasional temperature extremes of -80°F to +165°F, and flight bomb-bay temperatures of -90°F. It was pointed out that external bomb carriage might experience even more rigorous conditions of -100°F during a 12-hour flight, and that the 24-hour limitation regarding weapon assembly would be operationally troublesome.[40]

Inasmuch as the propellant characteristics were specified by the Bureau of Ordnance, the problem was referred to this organization.[41] It was noted that the environmental criteria had been specified after detail design of the Mk 8 had been essentially completed, and that these criteria differed considerably from the initial Mk 8 development objectives. It was also pointed out that any project to provide a propellant with improved temperature characteristics would duplicate work being undertaken in the TX-11 program. The Bureau of Ordnance subsequently allowed relaxation of the temperature limitations to 7 days at 130°F, 60 days at 120°F, and indefinitely at 110°F.[42] On March 12, 1953, the Military Liaison Committee agreed that major redesign efforts toward relieving temperature limits be directed toward the TX-11.[43]

The possibility of water leakage into the interior of the gun nuclear system had been a matter of early concern.

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When recovered, there was only about half a cup of water in the barrel, and this leakage was not felt great. Nevertheless, the Military, in the April 16, 1952 meeting of the Sandia Weapons Development Board, requested that the possible effects of this leakage on weapon performance be studied.[38]

Consequently, drops were made on a limestone bed in southwestern New Mexico. This rock possessed extremely high compressive strengths, from 18,000 to 23,000 pounds per square inch (average concrete strengths were about 4500 psi).

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Only one weapon showed any evidence of leakage. Experiments were started, using O-rings as replacements for the cork gaskets used to seal the openings in the bomb case.

It had been decided that the TX-8-X2 changes constituted a modification to the fuze rather than the bomb. Thus the Mk 8 Bomb with Mk 8 Mod 1 Fuze, incorporating a frangible nose and T-31 fuze tape control, was released for production and entered stockpile September 1953.

The TX-G Committee, whose functions had been largely assumed by the Special Weapons Development Board, was dissolved in January 1954. The Aspen Committee, which was directing Sandia-Los Alamos activities on the TX-11 weapon, agreed to handle any residual interlaboratory matters on the Mk 8 program.

(b)(3)

This change was made in the Mk 8 Mod 2 Bomb which was stockpiled in May 1955.

Meanwhile, studies had been made of the desirability of replacing the original Abner initiator with an improved design, the Phoebe. This change, plus the O-rings for sealing the bomb case, was known as the TX-8-X3 program during development.[44] Changes to the Atomic Energy Act permitted the Military to produce and stockpile certain atomic weapons parts, and it was suggested that the Bureau of Ordnance assume control of TX-8-X3 production work.[45] This proposal was rejected by the Atomic Energy Commission, which felt that close phasing was required, due to changes to both nuclear and nonnuclear portions of the Mk 8, and that Sandia should retain production control.[46] The Mk 8 Mod 3 was stockpiled in October 1955.

By February 1957, the Mk 11 Bomb was in production and entering stockpile. A decision was made to retire the Mk 8 weapons on a one-for-one basis as Mk 11's entered War Reserve. This retirement program started May 1957 and was completed 2 months later.

Mk 8 Warhead

The first consideration of a gun-type device for use with guided missiles was in a Los Alamos meeting of early March 1950, in which various missile programs were discussed.[47] Little immediate action was taken and, during the summer of that year,

attention was concentrated on developing the Elsie as a free-fall bomb to be released from aircraft. However, September 13, 1950, Santa Fe Operations Office requested Sandia and Los Alamos to consider the application of a penetrating warhead to various guided missiles. The missiles suggested were the HERMES A-3, HERMES C-1, REGULUS, RIGEL, and TRITON.[48]

It was obvious that a gun-type warhead would be more impact-resistant than an implosion design, and the request was referred to the Bureau of Ordnance, then doing work on the Mk 8 Bomb.

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Any missile usage would involve higher impact velocities and require new tests and additional design effort.[49] The Division of Military Application then referred the project to the Sandia Weapons Development Board, requesting that any Mk 8 Warhead developed be compatible with the above five missiles.[50]

Sandia made a preliminary study and, December 20, 1950, reported to the Santa Fe Operations Office that a firm estimate of the magnitude of the program could not be made. The terminal velocities of the missiles cited had not been definitely fixed, but were believed to be significantly greater than any previously considered in atomic-bomb design. Sandia proposed that a general investigation of impact warheads be continued, in an effort to delineate the most universally useful type of warhead and to outline a development program.[51]

The Santa Fe Operations Office suggested that initial application of the penetrating warhead be made to the REGULUS missile. This missile, scheduled for production in 1953, had a comparatively low impact velocity, and it was felt that a suitable warhead might be created by relatively simple modifications of existing components.[52] Sandia reported, January 23, 1951, that the development of such a warhead appeared feasible, and that the Bureau of Ordnance had been requested to investigate the effects of impact velocities and warhead mounting methods on the penetration characteristics of the Mk 8 device.[53]

The XW-8/REGULUS was authorized for design activity by the Santa Fe Operations Office February 14, 1951.[54] It was noted that since the REGULUS would attain an

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impact velocity of only Mach 1.2, there would be few shock problems, unless the weapon were employed against extremely hard targets such as igneous rock or heavy armor plate.[55]

It was determined that the fuzing accuracy for the XW-8/REGULUS could be less than for an air-burst device, since the only requirement was to initiate a pyrotechnic delay train about one minute prior to impact. Should the weapon be launched from a submarine, a simple arming system would protect the submarine against premature detonations.

The Sandia Weapons Development Board discussed the Mk 8 missile-warhead program in its April 10, 1951 meeting. It was felt that current weapon capabilities would not allow impact velocities higher than Mach 2.5 without danger of breakup of the device. Since the terminal velocity of the HERMES was estimated to be Mach 4.5, it was obvious that radical changes to either warhead or missile would have to be made if this missile were used. It was apparent that either approach would require much design investigation, and it was decided to consider only the XW-8/REGULUS.[56]

It was found that the warhead compartment of the REGULUS was long enough to hold the basic Mk 8 Bomb assembly, but that little excess clearance was available, and that access to the nose of the weapon was difficult. Additionally, the center of gravity of the missile would be about 30 inches forward of its optimum location, and it was decided to delete the afterbody of the Mk 8. Tests were started to determine the terraballistics of the Mk 8 without its afterbody, and to ascertain whether the warhead would break away from the missile on impact with various surfaces.[57]

Another problem was the development of a mechanism to ignite the propellant of the internal gun device of the XW-8/REGULUS. In the drop bomb, this was accomplished by arming tapes, but the warhead application required either a device to pull the tapes at the proper point in the missile trajectory or a modification of the fuze.

yield would be the same as that of the Mk 8 Bomb. The warhead would function properly when subjected to missile impact speeds up to Mach 1.1 on water, earth, reinforced concrete and, if possible, harder targets. It would not broach or ricochet after impacts at angles between 60 and 90 degrees. The weapon would penetrate the target and detonate after coming to rest, and would be sufficiently watertight to function after water impact, followed by bottom impact.[64]

The Military Liaison Committee notified the Division of Military Application, October 3, 1952, that no requirement existed for design of penetration warheads capable of impact velocities higher than those of the REGULUS missile.[65]

Meanwhile, the Military decided that efficient use of the XW-8/REGULUS weapon required a high delivery accuracy. This was not possible with the existing missile system, and production requirements were deferred, awaiting refinement of the missile guidance system. Sandia was requested to complete its design work on the warhead, and the Navy was asked to proceed with scheduled flight tests.[66]

Successful component evaluation flights were conducted, and a successful warhead system test was held September 24, 1953. The Military Liaison Committee then suggested that, since there were few differences between the XW-8 Warhead and the extensively tested Mk 8 Bomb, further systems tests be held in abeyance.[67]

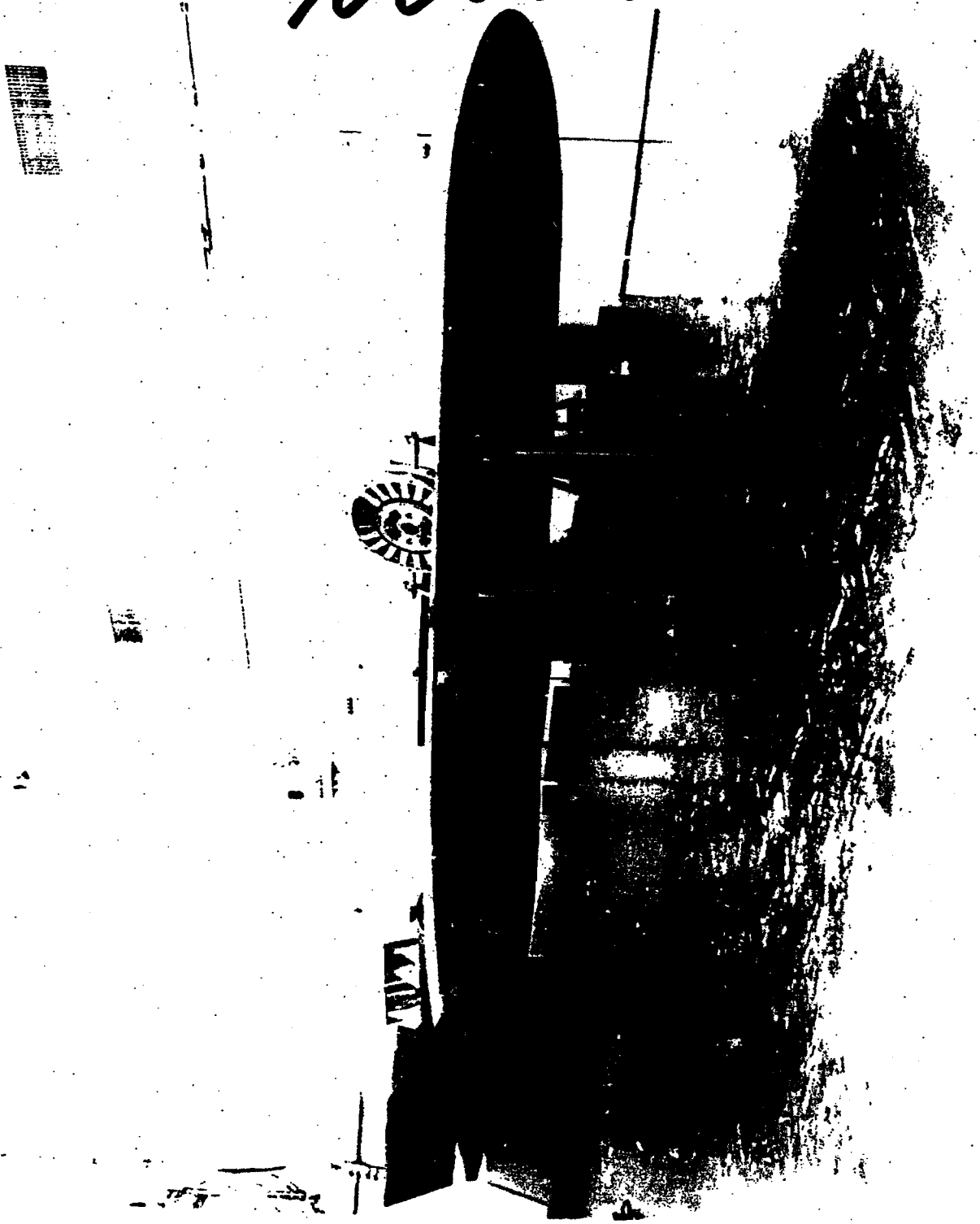
Design of the missile-warhead was completed in August 1954, and Report SC3483(TR), Status and Evaluation of the XW-8/REGULUS Warhead Installation at Design Release, was presented to the December 1, 1954 meeting of the Special Weapons Development Board.[68] The warhead was named the Mk 8 Mod 2, and production responsibility assigned to the Bureau of Ordnance.

The warhead contained three delay fuzes, two located on the side and one on the nose. (b)(3)

All requirements of the military characteristics were satisfied by the test program, although impact tests at less than 90 degrees were not conducted, and it was

not definitely determined whether the warhead would penetrate the target or break away on impact. However, Mk 8 Bomb tests had shown that satisfactory penetrations were achieved at entry angles as low as 30 degrees to the surface, and it was felt that the warhead would have similar satisfactory characteristics.

Subsequently, the possibility of developing a guidance system to effectively deliver the XW-8/REGULUS with pinpoint accuracy appeared remote. Consequently, on May 20, 1955, the Navy suspended activity in the program, together with work on the XW-11/REGULUS application.[69]



TX-10 External View

Subsequently, the Division of Military Application proposed that a lightweight, air-burst, gun-type missile warhead be developed,[74] and this suggestion received the backing of the Military Liaison Committee July 6, 1950.[75] It was proposed that Army Ordnance, then involved with the Mk 9 Shell, be requested to assist in design and development.[76]

Meanwhile, the lightweight, air-burst, gun-type bomb project had not been entirely forgotten, and the Military Liaison Committee, in a letter dated August 9, 1950, stated that the Joint Chiefs of Staff had established a requirement for the development of air-burst bombs sufficiently light in weight and small in cross section to be carried by high-speed tactical airplanes of the Air Force and Navy. It was felt that these bombs could be based on either implosion- or gun-type nuclear devices, and formal requests were made for both types.[77]

The subject was discussed in the August 16, 1950 meeting of the Sandia Weapons Development Board, with the Board agreeing to assume cognizance of the project. Two problems were immediately apparent: The development of a flexible fuzing system capable of attacking various tactical targets, and a weapon resistant to temperatures as low as -100°F.[78]

Sandia had meanwhile made a study of a lightweight bomb design and reported to AEC-Sandia August 17, 1950, that this could be produced by mid-1952. It was suggested that North American Aviation, Inc., be assigned the task of developing and manufacturing the outer case, internal support structures, and parts of the carrying pylon. Sandia would develop a fuzing and firing system, conduct drop tests, provide test and handling equipment, and act as project coordinator.[79]

On the same date, the Division of Military Application forwarded military characteristics for the above bomb. These required that the bomb be capable of tactical use by fighter, light bombardment, and attack (dive bomber) aircraft. The primary requirement was for external carriage, with alternate internal carriage being desired.

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The TX-G or Gun Committee agreed to accept interlaboratory responsibility for the TX-10.[26] The program was subjected to an intensive review in a Committee meeting of December 14, 1950, with the TX-10 being compared with the TX-7, an implosion design that had been pushed rapidly and which was now scheduled to enter stockpile earlier than the TX-10. It was felt by some conferees that the basic need for the TX-10 was eliminated by the advent of the TX-7. This latter weapon was larger than the proposed diameter of the TX-10 (27 inches versus 17 inches), but there appeared to be a sufficient variety of airplanes that could carry the TX-7.

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The problem was referred to the Sandia Weapons Development Board and discussed in a meeting December 20, 1950, with the Board being furnished copies of Sandia Report SC-1684(TR), A Critical Comparison Between the TX-7 and TX-10 Programs. This report noted that design was in work on a follow-on (and smaller) implosion device for the TX-7 (to be called the TX-12). The TX-12 would be less costly from the nuclear standpoint, would offer greater chances of increasing nuclear efficiency, and could be developed in about the same time scales. It was pointed out that work on the TX-10 would subtract effort from the TX-12, and that tactical use of the TX-10 (if manufactured in large numbers) would require major realignment of component production.

The Board noted that the TX-10 diameter would probably be smaller than the TX-7 or TX-12, but stated that further reductions in implosion-weapon diameter could be expected, as much nuclear design effort was currently being placed on implosion design improvements. After extensive discussion, the Board recommended that the TX-10 development be dropped in favor of the TX-12.[89]

The Division of Military Application wrote to Santa Fe Operations Office January 3, 1951, making reference to the above meeting. There were hopes that an interim TX-10 could be made available earlier than the TX-12, and it was suggested that the requirement for nuclear safing be eliminated and an external shape suitable for subsonic (but not necessarily supersonic) carriage be provided.[90]

The design status of the TX-10 was reviewed in the April 10, 1951 meeting of the Sandia Weapons Development Board. The bomb would be at least 17 inches in diameter and 2000 pounds in weight.

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The Board noted that the diameter and weight of the TX-10 exceeded the military characteristics, and that major reductions in these items could not be expected until the nuclear gun design was revised by Los Alamos.

(b)(3)

The project thus reverted to fundamental study of the problems of providing low burst heights, miniaturization, supersonic aerodynamics, and nuclear design improvements. Subsequently, the Military Liaison Committee canceled the TX-10 Bomb program May 7, 1952, noting that the Joint Chiefs of Staff had stated that a military requirement for the weapon no longer existed.

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Mk 11 Weapon

The Mk 11 Bomb, a gun-type penetrating weapon to be externally carried on high-speed aircraft, had its early beginnings when the gun-type device was considered for guided-missile application in March 1950. In this usage nuclear safing would be required to protect the missile launching site, and it would be necessary for the warhead to survive high impact velocities.[47]

Subsequently, the Division of Military Application expressed interest in a gun-type bomb that could be nuclearly safed and externally carried on high-speed aircraft.[99] The external shape of the Mk 8 did not lend itself to such carriage (due chiefly to its blunt nose), and it was felt that any modification of the nose shape would be complicated by the existence of the nose fuze. A nose redesign would require a lengthy effort, and it was suggested that a development program be authorized for a Mk II Elsie for such usage.[100]

The Military Liaison Committee released a set of desired military and technical characteristics for impact, delayed-action atomic bombs April 17, 1950. These characteristics described a bomb which could be nuclearly safed during aircraft carriage and that would be suitable for release at speeds up to Mach 1.2.[54] Subsequently, July 31, 1950, the Division of Military Application requested the Bureau of Ordnance to design a Mk 8-type weapon meeting these characteristics, and offered Sandia assistance in the task of fitting the design to appropriate carrying aircraft.[101] This proposal was accepted by the Bureau of Ordnance,[102] and nomenclature of TX-11 was assigned to the project November 29, 1950.[103]

There were three main gun-weapon problems being studied at this time: The ballistics problem relating to external carriage and release at high speeds; the nuclear safing problem, which concerned missiles as well as bombs; and the problem of increasing the resistance of the weapon to impacts on hard targets, such as reinforced concrete, rock and armor plate.

The Naval Ordnance Laboratory started to design the TX-11 fuzing system. It was felt that feasibility and preliminary design studies to establish tentative characteristics could be completed by January 1, 1952; and that detailed design

toss, glide and dive bombing. It would be capable of carriage and release at speeds up to Mach 1.4 and altitudes of 50,000 feet. It would be able to function satisfactorily after impacts on water, soil, reinforced concrete, and--to the extent practicable--harder targets.

The Board noted that the characteristics required external carriage at both subsonic and supersonic speeds, but a shape designed for one of these velocities would not be optimum for the other. It was felt that the design should be based on the assumption that the least drag during the major portion of the flight was desirable. Inasmuch as jet fighters en route to a target cruised at subsonic speeds, the bomb shape should be designed to meet this requirement.

The desire that the weapon be capable of penetration into hard rock was of concern. It was difficult to suitably define "hard rock," and there was felt to be a low incidence of this type of terrain near any probable targets. The scheduled design-release date was established as October 1953, with the bomb to enter stockpile in January 1955.[34]

The Bureau of Ordnance had been conducting tests of a soft-steel nose cap which, it was hoped, would crush and absorb the shock of weapon impact. These tests were not encouraging, and it was eventually decided to provide a Fiberglas nose cap. When the bomb was to be carried in an internal bomb bay, this nose cap could be removed.

Wind-tunnel tests had meanwhile narrowed the choice of weapon length to two possibilities; 146 and 169 inches. The Bureau of Ordnance recommended that the shorter figure be selected: It caused less drag at subsonic speed, it was compatible with all aircraft being considered for carriage of the bomb, and it could be carried internally in all aircraft except the B-50 without removing the nose cap.[109]

Full-scale drops at Inyokern produced excellent results.

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No detonation of the high explosive occurred during any of the impacts. Tests of 6-1/4-inch-diameter scale models against reinforced concrete 10 feet thick demonstrated that impact velocities between 2000 and 2200 feet per second could be

absorbed.[110] As a result of these tests, the length of the TX-11 was frozen at 146 inches on June 30, 1952, and the fin size was established at two bomb diameters, or 28 inches.[111]

Meanwhile, work had been undertaken on the design of a nuclear safing system,

(b)(3)

The fuzes were mechanically armed and were of a pyrotechnic design similar to those used in the Mk 8.

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Glossary of Terms

Ad Hoc Working Group -- A group established by the Guided Missiles Committee to oversee the design of one particular missile-warhead installation.

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions related to atomic weapons.

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Contact Fuze -- A fuze that detonates the weapon by contact with the ground or target.

Crossroads -- Full-scale tests of Mk III Bombs, held at the Pacific Proving Grounds. The Bikini Baker shot was held July 25, 1946. Much effects data were gained, and the shot was so destructive that a scheduled deep underwater burst was canceled.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

Drag -- Resistance created by the passage of a shape through the air.

Field Command -- The local office of the Armed Forces Special Weapons Project, located on Sandia Base, Albuquerque, New Mexico.

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Joint Research and Development Board -- A Board established in mid-1946 as a postwar replacement for the Office of Scientific Research and Development. Its purpose was to suggest lines of research and development on military weapons and equipment.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Little Boy -- Code name for the gun-type weapon dropped on Hiroshima, Japan, August 6, 1945, during World War II. Originally called the Thin Man in reference to its long thin shape. The Thin Man was to use plutonium-239 as its nuclear material. Early samples of this isotope revealed that it contained small amounts of plutonium-240 which had a high preinitiation rate. A decision was then made to use uranium-235, allowing the length of the weapon to be radically reduced (due to the lower speed of assembly of the critical material). This change in outer shape was given the code name of Little Boy.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico. Called the Los Alamos Laboratory during World War II.

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Manhattan Engineer District -- A District of the Army Engineers established in August 1942 to provide the facilities that would be needed for design and construction of the atomic bomb.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

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Naval Ordnance Laboratory -- A portion of the Bureau of Ordnance devoted to design and test of Naval ordnance.

Neutron -- An uncharged particle of slightly greater mass than the proton.

Operation Crossroads -- See Crossroads.

Pitch -- Motion of the bomb as it falls through the air, such that the nose and tail alternately rise and fall.

Proton -- The nucleus of the atom of the light isotope of hydrogen. It has a unit positive charge of electricity.

Prototype -- An early weapon type, generally hand-produced before a production run.

Pylon -- A strut to hold bomb in position below an airplane wing.

Pyrotechnic Fuze -- A fuze that operates by burning or detonation of a small charge of explosive.

Radar -- Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Ricochet -- A glancing rebound of a missile when it strikes a target.

Safing -- Putting a weapon in condition such that it cannot fire.

Salton Sea Test Base -- Located on the site of a Naval Auxiliary Air Station on the shores of Salton Sea, California. One of the early sites for ballistic tests of atomic bombs.

Sandia Research and Development Board -- A joint Sandia-Military board formed March 2, 1948, at Sandia Base to provide local guidance on weapons design.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent of uranium-238; the rest is uranium-235.

Z Division -- A division of the Los Alamos Scientific Laboratory, elements of which moved to Sandia Base and became the nucleus of Sandia Laboratory and Corporation.

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AEC ATOMIC WEAPON DATA
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HISTORY OF GUN-TYPE BOMBS AND WARHEADS (W)

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Mk 8 Exterior View

THE TX-8 BOMB

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(b)(1), (b)(3)

LENGTH—116 IN
DIAMETER—14.5 IN.
WEIGHT—3150 LBS

Mk 8 Cross Section

12/8/50	TX-G Steering Committee appointed and holds initial meeting.
1/26/51	
	(b)(3)
3/15/51	
Early 1951	Externally carried TX-8 Bomb assigned nomenclature of TX-8 Prime.
10/51	TX-8 Prime program divided into two parts: TX-8-X1 (to cover carriage at subsonic speeds) and TX-8-X2 (a program to reduce drag in high-speed carriage).
11/51	Mk 8 Mod 0 achieves production.
1/52	Mk 8 Mod 0 enters stockpile.
4/1/52	
	(b)(3)
9/53	Mk 8 Bomb with Mk 8 Mod 1 Fuze (TX-8-X2) enters stockpile.
11/55	Mk 8 Mod 3 Bomb enters stockpile.
5/57	Mk 8 Bombs retired as Mk 11 enters stockpile.

Mk 8 Warhead

3/50	Gun-type warheads considered for missile application.
9/13/50	Santa Fe Operations Office requests that penetrating warheads be applied to guided missiles.
2/14/51	Santa Fe Operations Office authorizes design of XW-8/REGULUS.
1/18/52	XW-5/REGULUS program assigned priority over XW-8/REGULUS.
8/21/52	Field Command forwards proposed military characteristics for XW-8/REGULUS to Sandia.
9/24/53	Successful XW-8/REGULUS system test held.

8/54 Design of XW-8/REGULUS completed.

5/20/55 Program activity suspended.

TX-10 Weapon

5/6/48 Sandia Research and Development Board assigns priorities to weapon design projects.

1/21/49 Division of Military Application requests Bureau of Ordnance to study possible adaptation of Mk 8 as a light air-burst weapon.

4/22/49 Military Liaison Committee requests that study be restricted to a preliminary investigation.

3/8/50 Guided-missile symposium at Sandia Base proposes use of a light-weight gun-type device as a missile warhead.

7/6/50 Military Liaison Committee releases formal requirement for an air-burst, gun-type warhead.

8/9/50 Military Liaison Committee establishes formal requirement for a lightweight air-turst bomb.

8/17/50 Division of Military Application forwards characteristics for lightweight air-burst bombs.

9/6/50 Bureau of Ordnance, in reply to January 21, 1949 request of the Division of Military Application, offers to adapt the Mk 8 as a lightweight air-burst bomb.

10/3/50 Division of Military Application notifies Bureau of Ordnance that Sandia will develop the lightweight air-burst bomb.

10/18/50 Sandia Weapons Development Board discusses bomb and warhead applications. Santa Fe Operations Office subsequently authorizes deletion of warhead requirement. Bomb officially designated the TX-10.

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4/1/55 Mk 11 design released.

1/1/56 Early production units of Mk 11 (Mk 91 Mod 0) become available.

7/1/56 Mk 91 Mod 0 enters stockpile.

8/56

(b)(3)

History of Gun-Type Bombs and Warheads

Mk 8 Bomb

The gun method of assembling nuclear material, used in the wartime Little Boy design, was the first atomic weapon system to be devised, predating the establishment of the Los Alamos Laboratory. The method was nuclearly inefficient and was largely ignored for a time after the end of World War II, while interest centered on implosion techniques.

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At this time, the Los Alamos Scientific Laboratory was fully occupied in the above-mentioned study of improvements in implosion devices, and suggested that the task of developing a water-penetrating weapon (which probably would use gun techniques) could best be accomplished by a military group. No immediate action was taken on this suggestion, but the subject was briefly examined by the Z Division of Los Alamos in late 1946 and early 1947.

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The topic was subsequently discussed in a meeting of the Weapons Subcommittee of the AEC General Advisory Committee, and a decision made May 15, 1947 that consideration of a penetrating weapon be postponed.[4]

Meanwhile, however, the Military Liaison Committee had been discussing the general subject of subsurface atomic weapons. At the instigation of the Navy member, Rear Admiral William S. Parsons (who had armed the wartime gun-type Little Boy for

its historic drop on Hiroshima), Section ReM of the Navy's Bureau of Ordnance, prepared preliminary sketches of a penetrating gun device.

At about the same time, other groups were considering the same subject. The Joint Research and Development Board had established a Committee on Atomic Energy, and the subject of penetrating weapons was discussed in the October 2, 1947 meeting of this Committee. It was urged that serious consideration be given to the development of a gun-type device suitable for penetration use. Since the AEC weapon laboratories were already fully occupied with other high-priority work, the Committee recommended that the facilities of the Bureau of Ordnance be used.[5]

The Division of Military Application had also been considering the advisability of invoking the assistance of the military services in the development of penetrating weapons. Los Alamos had noted that gun systems were inherently inefficient, and expressed an opinion that the weapons laboratories should continue to concentrate on design of implosion devices.[6] Thus the Military Liaison Committee was requested to assign mechanical design of a gun-type penetration weapon to the Bureau of Ordnance.[7]

These several requests, all in the same vein, were presented for consideration to the Military Liaison Committee which, April 9, 1948, requested the Atomic Energy Commission to undertake development of a penetrating-type weapon, using the facilities of the Bureau of Ordnance.[8] This request was formally presented to the Bureau April 27, 1948, and accepted.[9] A code name of "Minnie" was initially assigned to the project, but was later found to have been used for a Bureau of Ships propulsion project and, in mid-July 1948, the name was changed to "LC" (a follow-on term to "LB," for the Little Boy), and which came to be commonly written as "Elsie."[10] That the Elsie program was considered a matter of some interest to the Military was indicated in a May 6, 1948 meeting of the Sandia Research and Development Board in which the project was assigned top priority, second only to the schedule for getting the Mk 4 Bomb into full-scale production.

The Bureau of Ordnance issued detailed work assignments. The Naval Ordnance Laboratory would be responsible for developing suitable pyrotechnic delay fuzes.

The Naval Ordnance Test Station would study external ballistics and design the tail. The Naval Powder Factory would investigate powder development. The Naval Ordnance Plant would handle much of the manufacturing and testing program, and when this location was subsequently closed, the work would be transferred to the Naval Proving Grounds and the Naval Gun Factory. Section ReM of the Bureau of Ordnance would provide overall design controls, including the task of guaranteeing survival of the nuclear assembly under impact conditions.

The development program would proceed in three overlapping phases. Feasibility and preliminary design studies would outline the most promising general design characteristics of the weapon, and these were scheduled for completion January 1, 1949. The second phase, covering experimental development and testing of prototype weapon design, would be completed a year later. The third phase, manufacture of prototype weapons, would be finished in another year, or January 1, 1951.

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The studies advanced rapidly and, by September 3, 1948, the Bureau of Ordnance could report that the design appeared feasible and that a weapon could probably be devised that would function satisfactorily after impact on water, and possibly after impact on hard surfaces which the weapon might encounter beneath the surface of the water.[11] It was initially felt that the fuze should be actuated at impact and have a delay of 1 to 2 minutes before bomb detonation, but it was later decided that a more reliable bomb would be created if the fuze action were initiated at time of release of the bomb from the carrying aircraft.

The diameter of the bomb would be about 14 inches and the weight would be about 3000 pounds, as compared to 28 inches and 8900 pounds for the Little Boy. These reductions were due to the more compact nuclear assembly and a decrease in the thickness of the bomb case. The shape would be roughly cylindrical, with a flat nose for good penetration characteristics, and the bomb would attain a maximum impact velocity of 1500 feet per second. The minimum release altitude would be 500 feet, to give the bomb enough time during its fall to assume proper entry attitude, and there would be no restriction on maximum release altitude. It was felt that three separate and independent fuzes should be used, to provide adequate relisbility. A meeting was held October 25 and 26, 1948, with Los Alamos assuming the task of developing impact-resistant initiators.[12]

An extensive series of tests was performed. The first group included 174 half-scale bombs of 6.25-inch diameter. These were fabricated in 49 different configurations, and were impacted against targets of steel and concrete at different angles, striking velocities, and missile temperatures ranging from -65°F to +165°F.

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Following the above, some 38 full-scale impact tests were conducted, to confirm the half-scale results. Interior ballistic tests were performed, to check the burning rate of various propellants and the behavior of the missile in the gun barrel. As fuze components became available, they were subjected to the shock produced by firing from a 14.25-inch-diameter railway gun.

Two series of wind-tunnel tests were held, one at the University of Minnesota to obtain aerodynamic coefficients of various tail configurations, and the other at the California Institute of Technology Cooperative Wind Tunnel to evaluate aerodynamic characteristics of five basic designs.

directive was issued August 30, 1950, accompanied by a request that the facilities of the Bureau of Ordnance be used to the fullest extent possible.[17] At this time, the Elsie was assigned nomenclature of TX-8.[18]

An intensive study had been undertaken of changes required to allow external carriage of the TX-8. There were several reasons why these changes were necessary. For one, the fuze system had been designed to operate under protected bomb-bay conditions. For another, the shape of the TX-8, with its blunt nose, caused excessive drag, especially at high speeds.

(b)(3)

It was obvious that this would require considerable study, and it was suggested that the Bureau of Ordnance establish a parallel program for the development of a Mk II Elsie suitable for either internal or external suspension, while work continued on an internally carried TX-8.[19]

The Bureau made a survey and reported that the existing shape of the TX-8 was adequate for subsonic external carriage if some minor changes were made to the tail design,[20] and the shape could be carried in the space available under the centerline of the F4U, AD and A2D airplanes. It was noted that development of a shape for external carriage at supersonic velocities would require additional study and development, and this effort would be of interest in connection with a recent proposal that an XW-8 Warhead be fitted to a guided missile. Subsequently, October 3, 1950, the Division of Military Application authorized development of an externally carried TX-8 with subsonic aircraft and development of a new bomb (the TX-11) for high-speed external carriage.[21]

Meanwhile, the Armed Forces Special Weapons Project had been drawing up a paper specifying the desired military and technical characteristics of penetrating-type weapons.

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This paper was circulated for comment to Sandia and Los Alamos as well as the Military, and was subjected to a critical review.[23] The formal issue of the characteristics on November 10, 1950, however, retained the release speed requirement and noted that the bomb should function reliably when released at any altitude up to 50,000 feet and survive impacts on water, reinforced concrete, and--hopefully--thin steel plate.

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The November 22, 1950 meeting of the Sandia Weapons Development Board reviewed the overall gun-type weapons program, which now included the TX-9, TX-10, and TX-11, in addition to the TX-8. It was noted that the TX-8 was composed of three main parts: The nose, the tail, and the clamping ring which joined them. The bomb diameter had been fixed at 14.5 inches, its length at 116 inches, and its weight at 3260 pounds. The nose was a heavy forging with a blunt shape for water and ground entry, and contained the internal gun barrel, tamper, and projectile.

(b)(3)

A saddle on the external top of the bomb case contained switches and electrical connections to operate the primers.[25]

Sandia had proposed that an interlaboratory gun-type weapon coordination committee be established, similar in scope and authority to the TX-5 Steering Committee. Action was taken on this suggestion in late 1950, and the first meeting of this Gun Committee, with representation from Los Alamos and Sandia, was held December 8, 1950.[26] At this time, the TX-5 Steering Committee was renamed the TX-N Steering Committee to reflect its interest in all implosion weapons, and the new Gun Committee came to be known as the TX-G Steering Committee.

The first meeting of the TX-G Committee heard a report from Los Alamos concerning progress on design of an initiator for the TX-8. The initial design had been based on the device used in the Little Boy, and was then modified as design weaknesses were uncovered by the testing program. Some idea of the problems encountered were shown by the increasing impact requirements as the design progressed. The initial

assumption had been that the highest shock encountered in ground impact would be 7500 g's. This figure had progressively increased during design and was now 100,000 to 300,000 g's.

(b)(3)

Studies were meanwhile in progress on systems for nuclear safing.

(b)(3)

In early 1951 it was decided to identify the adaptation of the TX-8 for external carriage at subsonic speeds as the TX-8' (or TX-8 Prime) program. Plans were made to make only minor changes to the TX-8 and provide early, but only partial, satisfaction of the requirements for an externally carried TX-8. It was felt that, if this program could not be accomplished within a short time, it should be canceled in favor of the TX-11 Bomb, then being designed for external carriage on high-speed aircraft.

At this time, the AD4 and the F4U5 were the only carriers specified for the TX-8'. The AD4 was selected as the test aircraft, and Sandia issued a contract through the Bureau of Aeronautics to Douglas Aircraft Company to modify this aircraft for TX-8 carriage. Douglas designed a nose cap to reduce drag and help protect the TX-8' fuzing elements.

In late October 1951, the TX-8' program was divided into two parts; the TX-8-X1 and TX-8-X2. The X1 was the basic TX-8' program; the X2 was to provide a cleaner aerodynamic design and reduce the drag caused by the saddle. Inasmuch as 20 drops had already been made with the TX-8-X1, its compatibility and reliability were felt to have been proven, and attention was concentrated on the TX-8-X2 design.[33]

The T-28 saddle functions were replaced by a small box located in the aircraft fuselage. This allowed the use of a standard two-hook bomb rack and increased the clearance between the externally carried bomb and the ground. Fairings were installed over the side fuzes to reduce drag. Fuze tapes used for safing were pulled through the nose fairing to protect them from the windstream. A quick disconnect was installed, to permit the weapon to be dropped with tapes in place, thus leaving barriers in the path between the primer and the propellant, and preventing the fuzes from firing the main propellant charge.

This new device was called the T-31, and a subcontract was issued for its development. Due to the subsequent failure of the subcontractor to achieve a satisfactory T-31, Sandia produced a design having the T-31 located inside the bomb pylon, thus making it possible to detach the arming tapes from the pylon after bomb release, and prevent aircraft damage caused by whipping of the tapes in the slipstream. This work was undertaken November 5, 1951, and satisfactory hardware was being produced 10 days later.

The Mk 8 Mod 0 weapon was initially produced in November 1951 and was stockpiled in January 1952.

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The Military Liaison Committee, in a letter dated October 20, 1952, requested that the bomb be designed to withstand storage for 6-month periods under occasional temperature extremes of -80°F to +165°F, and flight bomb-bay temperatures of -90°F. It was pointed out that external bomb carriage might experience even more rigorous conditions of -100°F during a 12-hour flight, and that the 24-hour limitation regarding weapon assembly would be operationally troublesome.[40]

Inasmuch as the propellant characteristics were specified by the Bureau of Ordnance, the problem was referred to this organization.[41] It was noted that the environmental criteria had been specified after detail design of the Mk 8 had been essentially completed, and that these criteria differed considerably from the initial Mk 8 development objectives. It was also pointed out that any project to provide a propellant with improved temperature characteristics would duplicate work being undertaken in the TX-11 program. The Bureau of Ordnance subsequently allowed relaxation of the temperature limitations to 7 days at 130°F, 60 days at 120°F, and indefinitely at 110°F.[42] On March 12, 1953, the Military Liaison Committee agreed that major redesign efforts toward relieving temperature limits be directed toward the TX-11.[43]

The possibility of water leakage into the interior of the gun nuclear system had been a matter of early concern.

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When recovered, there was only about half a cup of water in the barrel, and this leakage was not felt great. Nevertheless, the Military, in the April 16, 1952 meeting of the Sandia Weapons Development Board, requested that the possible effects of this leakage on weapon performance be studied.[38]

Consequently, drops were made on a limestone bed in southwestern New Mexico. This rock possessed extremely high compressive strengths, from 18,000 to 23,000 pounds per square inch (average concrete strengths were about 4500 psi).

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Only one weapon showed any evidence of leakage. Experiments were started, using O-rings as replacements for the cork gaskets used to seal the openings in the bomb case.

It had been decided that the TX-8-X2 changes constituted a modification to the fuze rather than the bomb. Thus the Mk 8 Bomb with Mk 8 Mod 1 Fuze, incorporating a frangible nose and T-31 fuze tape control, was released for production and entered stockpile September 1953.

The TX-G Committee, whose functions had been largely assumed by the Special Weapons Development Board, was dissolved in January 1954. The Aspen Committee, which was directing Sandia-Los Alamos activities on the TX-11 weapon, agreed to handle any residual interlaboratory matters on the Mk 8 program.

(b)(3)

This change was made in the Mk 8 Mod 2 Bomb which was stockpiled in May 1955.

Meanwhile, studies had been made of the desirability of replacing the original Abner initiator with an improved design, the Phoebe. This change, plus the O-rings for sealing the bomb case, was known as the TX-8-X3 program during development.[44] Changes to the Atomic Energy Act permitted the Military to produce and stockpile certain atomic weapons parts, and it was suggested that the Bureau of Ordnance assume control of TX-8-X3 production work.[45] This proposal was rejected by the Atomic Energy Commission, which felt that close phasing was required, due to changes to both nuclear and nonnuclear portions of the Mk 8, and that Sandia should retain production control.[46] The Mk 8 Mod 3 was stockpiled in October 1955.

By February 1957, the Mk 11 Bomb was in production and entering stockpile. A decision was made to retire the Mk 8 weapons on a one-for-one basis as Mk 11's entered War Reserve. This retirement program started May 1957 and was completed 2 months later.

Mk 8 Warhead

The first consideration of a gun-type device for use with guided missiles was in a Los Alamos meeting of early March 1950, in which various missile programs were discussed.[47] Little immediate action was taken and, during the summer of that year,

attention was concentrated on developing the Elsie as a free-fall bomb to be released from aircraft. However, September 13, 1950, Santa Fe Operations Office requested Sandia and Los Alamos to consider the application of a penetrating warhead to various guided missiles. The missiles suggested were the HERMES A-3, HERMES C-1, REGULUS, RIGEL, and TRITON.[48]

It was obvious that a gun-type warhead would be more impact-resistant than an implosion design, and the request was referred to the Bureau of Ordnance, then doing work on the Mk 8 Bomb.

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Any missile usage would involve higher impact velocities and require new tests and additional design effort.[49] The Division of Military Application then referred the project to the Sandia Weapons Development Board, requesting that any Mk 8 Warhead developed be compatible with the above five missiles.[50]

Sandia made a preliminary study and, December 20, 1950, reported to the Santa Fe Operations Office that a firm estimate of the magnitude of the program could not be made. The terminal velocities of the missiles cited had not been definitely fixed, but were believed to be significantly greater than any previously considered in atomic-bomb design. Sandia proposed that a general investigation of impact warheads be continued, in an effort to delineate the most universally useful type of warhead and to outline a development program.[51]

The Santa Fe Operations Office suggested that initial application of the penetrating warhead be made to the REGULUS missile. This missile, scheduled for production in 1953, had a comparatively low impact velocity, and it was felt that a suitable warhead might be created by relatively simple modifications of existing components.[52] Sandia reported, January 23, 1951, that the development of such a warhead appeared feasible, and that the Bureau of Ordnance had been requested to investigate the effects of impact velocities and warhead mounting methods on the penetration characteristics of the Mk 8 device.[53]

The XW-8/REGULUS was authorized for design activity by the Santa Fe Operations Office February 14, 1951.[54] It was noted that since the REGULUS would attain an

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impact velocity of only Mach 1.2, there would be few shock problems, unless the weapon were employed against extremely hard targets such as igneous rock or heavy armor plate.[55]

It was determined that the fuzing accuracy for the XW-8/REGULUS could be less than for an air-burst device, since the only requirement was to initiate a pyrotechnic delay train about one minute prior to impact. Should the weapon be launched from a submarine, a simple arming system would protect the submarine against premature detonations.

The Sandia Weapons Development Board discussed the Mk 8 missile-warhead program in its April 10, 1951 meeting. It was felt that current weapon capabilities would not allow impact velocities higher than Mach 2.5 without danger of breakup of the device. Since the terminal velocity of the HERMES was estimated to be Mach 4.5, it was obvious that radical changes to either warhead or missile would have to be made if this missile were used. It was apparent that either approach would require much design investigation, and it was decided to consider only the XW-8/REGULUS.[56]

It was found that the warhead compartment of the REGULUS was long enough to hold the basic Mk 8 Bomb assembly, but that little excess clearance was available, and that access to the nose of the weapon was difficult. Additionally, the center of gravity of the missile would be about 30 inches forward of its optimum location, and it was decided to delete the afterbody of the Mk 8. Tests were started to determine the terraballistics of the Mk 8 without its afterbody, and to ascertain whether the warhead would break away from the missile on impact with various surfaces.[57]

Another problem was the development of a mechanism to ignite the propellant of the internal gun device of the XW-8/REGULUS. In the drop bomb, this was accomplished by arming tapes, but the warhead application required either a device to pull the tapes at the proper point in the missile trajectory or a modification of the fuze.

yield would be the same as that of the Mk 8 Bomb. The warhead would function properly when subjected to missile impact speeds up to Mach 1.1 on water, earth, reinforced concrete and, if possible, harder targets. It would not broach or ricochet after impacts at angles between 60 and 90 degrees. The weapon would penetrate the target and detonate after coming to rest, and would be sufficiently watertight to function after water impact, followed by bottom impact.[64]

The Military Liaison Committee notified the Division of Military Application, October 3, 1952, that no requirement existed for design of penetration warheads capable of impact velocities higher than those of the REGULUS missile.[65]

Meanwhile, the Military decided that efficient use of the XW-8/REGULUS weapon required a high delivery accuracy. This was not possible with the existing missile system, and production requirements were deferred, awaiting refinement of the missile guidance system. Sandia was requested to complete its design work on the warhead, and the Navy was asked to proceed with scheduled flight tests.[66]

Successful component evaluation flights were conducted, and a successful warhead system test was held September 24, 1953. The Military Liaison Committee then suggested that, since there were few differences between the XW-8 Warhead and the extensively tested Mk 8 Bomb, further systems tests be held in abeyance.[67]

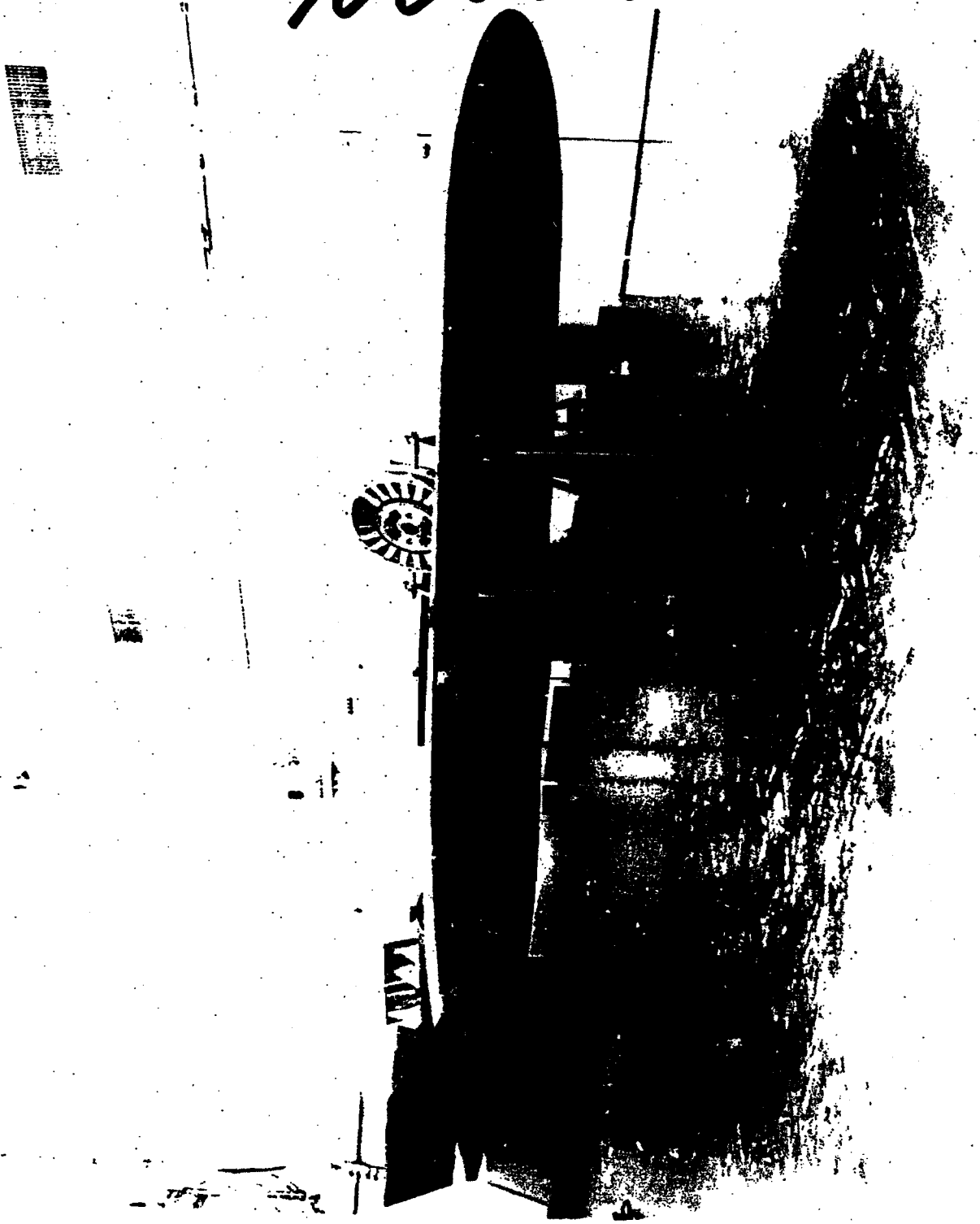
Design of the missile-warhead was completed in August 1954, and Report SC3483(TR), Status and Evaluation of the XW-8/REGULUS Warhead Installation at Design Release, was presented to the December 1, 1954 meeting of the Special Weapons Development Board.[68] The warhead was named the Mk 8 Mod 2, and production responsibility assigned to the Bureau of Ordnance.

The warhead contained three delay fuzes, two located on the side and one on the nose. (b)(3)

All requirements of the military characteristics were satisfied by the test program, although impact tests at less than 90 degrees were not conducted, and it was

not definitely determined whether the warhead would penetrate the target or break away on impact. However, Mk 8 Bomb tests had shown that satisfactory penetrations were achieved at entry angles as low as 30 degrees to the surface, and it was felt that the warhead would have similar satisfactory characteristics.

Subsequently, the possibility of developing a guidance system to effectively deliver the XW-8/REGULUS with pinpoint accuracy appeared remote. Consequently, on May 20, 1955, the Navy suspended activity in the program, together with work on the XW-11/REGULUS application.[69]



TX-10 External View

Subsequently, the Division of Military Application proposed that a lightweight, air-burst, gun-type missile warhead be developed,[74] and this suggestion received the backing of the Military Liaison Committee July 6, 1950.[75] It was proposed that Army Ordnance, then involved with the Mk 9 Shell, be requested to assist in design and development.[76]

Meanwhile, the lightweight, air-burst, gun-type bomb project had not been entirely forgotten, and the Military Liaison Committee, in a letter dated August 9, 1950, stated that the Joint Chiefs of Staff had established a requirement for the development of air-burst bombs sufficiently light in weight and small in cross section to be carried by high-speed tactical airplanes of the Air Force and Navy. It was felt that these bombs could be based on either implosion- or gun-type nuclear devices, and formal requests were made for both types.[77]

The subject was discussed in the August 16, 1950 meeting of the Sandia Weapons Development Board, with the Board agreeing to assume cognizance of the project. Two problems were immediately apparent: The development of a flexible fuzing system capable of attacking various tactical targets, and a weapon resistant to temperatures as low as -100°F.[78]

Sandia had meanwhile made a study of a lightweight bomb design and reported to AEC-Sandia August 17, 1950, that this could be produced by mid-1952. It was suggested that North American Aviation, Inc., be assigned the task of developing and manufacturing the outer case, internal support structures, and parts of the carrying pylon. Sandia would develop a fuzing and firing system, conduct drop tests, provide test and handling equipment, and act as project coordinator.[79]

On the same date, the Division of Military Application forwarded military characteristics for the above bomb. These required that the bomb be capable of tactical use by fighter, light bombardment, and attack (dive bomber) aircraft. The primary requirement was for external carriage, with alternate internal carriage being desired.

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The TX-G or Gun Committee agreed to accept interlaboratory responsibility for the TX-10.[26] The program was subjected to an intensive review in a Committee meeting of December 14, 1950, with the TX-10 being compared with the TX-7, an implosion design that had been pushed rapidly and which was now scheduled to enter stockpile earlier than the TX-10. It was felt by some conferees that the basic need for the TX-10 was eliminated by the advent of the TX-7. This latter weapon was larger than the proposed diameter of the TX-10 (27 inches versus 17 inches), but there appeared to be a sufficient variety of airplanes that could carry the TX-7.

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The problem was referred to the Sandia Weapons Development Board and discussed in a meeting December 20, 1950, with the Board being furnished copies of Sandia Report SC-1684(TR), A Critical Comparison Between the TX-7 and TX-10 Programs. This report noted that design was in work on a follow-on (and smaller) implosion device for the TX-7 (to be called the TX-12). The TX-12 would be less costly from the nuclear standpoint, would offer greater chances of increasing nuclear efficiency, and could be developed in about the same time scales. It was pointed out that work on the TX-10 would subtract effort from the TX-12, and that tactical use of the TX-10 (if manufactured in large numbers) would require major realignment of component production.

The Board noted that the TX-10 diameter would probably be smaller than the TX-7 or TX-12, but stated that further reductions in implosion-weapon diameter could be expected, as much nuclear design effort was currently being placed on implosion design improvements. After extensive discussion, the Board recommended that the TX-10 development be dropped in favor of the TX-12.[89]

The Division of Military Application wrote to Santa Fe Operations Office January 3, 1951, making reference to the above meeting. There were hopes that an interim TX-10 could be made available earlier than the TX-12, and it was suggested that the requirement for nuclear safing be eliminated and an external shape suitable for subsonic (but not necessarily supersonic) carriage be provided.[90]

The design status of the TX-10 was reviewed in the April 10, 1951 meeting of the Sandia Weapons Development Board. The bomb would be at least 17 inches in diameter and 2000 pounds in weight.

(b)(3), (b)(1)

The Board noted that the diameter and weight of the TX-10 exceeded the military characteristics, and that major reductions in these items could not be expected until the nuclear gun design was revised by Los Alamos.

(b)(3)

The project thus reverted to fundamental study of the problems of providing low burst heights, miniaturization, supersonic aerodynamics, and nuclear design improvements. Subsequently, the Military Liaison Committee canceled the TX-10 Bomb program May 7, 1952, noting that the Joint Chiefs of Staff had stated that a military requirement for the weapon no longer existed.

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Mk 11 Weapon

The Mk 11 Bomb, a gun-type penetrating weapon to be externally carried on high-speed aircraft, had its early beginnings when the gun-type device was considered for guided-missile application in March 1950. In this usage nuclear safing would be required to protect the missile launching site, and it would be necessary for the warhead to survive high impact velocities.[47]

Subsequently, the Division of Military Application expressed interest in a gun-type bomb that could be nuclearly safed and externally carried on high-speed aircraft.[99] The external shape of the Mk 8 did not lend itself to such carriage (due chiefly to its blunt nose), and it was felt that any modification of the nose shape would be complicated by the existence of the nose fuze. A nose redesign would require a lengthy effort, and it was suggested that a development program be authorized for a Mk II Elsie for such usage.[100]

The Military Liaison Committee released a set of desired military and technical characteristics for impact, delayed-action atomic bombs April 17, 1950. These characteristics described a bomb which could be nuclearly safed during aircraft carriage and that would be suitable for release at speeds up to Mach 1.2.[54] Subsequently, July 31, 1950, the Division of Military Application requested the Bureau of Ordnance to design a Mk 8-type weapon meeting these characteristics, and offered Sandia assistance in the task of fitting the design to appropriate carrying aircraft.[101] This proposal was accepted by the Bureau of Ordnance,[102] and nomenclature of TX-11 was assigned to the project November 29, 1950.[103]

There were three main gun-weapon problems being studied at this time: The ballistics problem relating to external carriage and release at high speeds; the nuclear safing problem, which concerned missiles as well as bombs; and the problem of increasing the resistance of the weapon to impacts on hard targets, such as reinforced concrete, rock and armor plate.

The Naval Ordnance Laboratory started to design the TX-11 fuzing system. It was felt that feasibility and preliminary design studies to establish tentative characteristics could be completed by January 1, 1952; and that detailed design

toss, glide and dive bombing. It would be capable of carriage and release at speeds up to Mach 1.4 and altitudes of 50,000 feet. It would be able to function satisfactorily after impacts on water, soil, reinforced concrete, and--to the extent practicable--harder targets.

The Board noted that the characteristics required external carriage at both subsonic and supersonic speeds, but a shape designed for one of these velocities would not be optimum for the other. It was felt that the design should be based on the assumption that the least drag during the major portion of the flight was desirable. Inasmuch as jet fighters en route to a target cruised at subsonic speeds, the bomb shape should be designed to meet this requirement.

The desire that the weapon be capable of penetration into hard rock was of concern. It was difficult to suitably define "hard rock," and there was felt to be a low incidence of this type of terrain near any probable targets. The scheduled design-release date was established as October 1953, with the bomb to enter stockpile in January 1955.[34]

The Bureau of Ordnance had been conducting tests of a soft-steel nose cap which, it was hoped, would crush and absorb the shock of weapon impact. These tests were not encouraging, and it was eventually decided to provide a Fiberglas nose cap. When the bomb was to be carried in an internal bomb bay, this nose cap could be removed.

Wind-tunnel tests had meanwhile narrowed the choice of weapon length to two possibilities; 146 and 169 inches. The Bureau of Ordnance recommended that the shorter figure be selected: It caused less drag at subsonic speed, it was compatible with all aircraft being considered for carriage of the bomb, and it could be carried internally in all aircraft except the B-50 without removing the nose cap.[109]

Full-scale drops at Inyokern produced excellent results.

(b)(1), (b)(3)

No detonation of the high explosive occurred during any of the impacts. Tests of 6-1/4-inch-diameter scale models against reinforced concrete 10 feet thick demonstrated that impact velocities between 2000 and 2200 feet per second could be

absorbed.[110] As a result of these tests, the length of the TX-11 was frozen at 146 inches on June 30, 1952, and the fin size was established at two bomb diameters, or 28 inches.[111]

Meanwhile, work had been undertaken on the design of a nuclear safing system,

(b)(3)

The fuzes were mechanically armed and were of a pyrotechnic design similar to those used in the Mk 8.

(b)(1), (b)(3)

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Glossary of Terms

Ad Hoc Working Group -- A group established by the Guided Missiles Committee to oversee the design of one particular missile-warhead installation.

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions related to atomic weapons.

(b)(1), (b)(3)

Contact Fuze -- A fuze that detonates the weapon by contact with the ground or target.

Crossroads -- Full-scale tests of Mk III Bombs, held at the Pacific Proving Grounds. The Bikini Baker shot was held July 25, 1946. Much effects data were gained, and the shot was so destructive that a scheduled deep underwater burst was canceled.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

Drag -- Resistance created by the passage of a shape through the air.

Field Command -- The local office of the Armed Forces Special Weapons Project, located on Sandia Base, Albuquerque, New Mexico.

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Joint Research and Development Board -- A Board established in mid-1946 as a postwar replacement for the Office of Scientific Research and Development. Its purpose was to suggest lines of research and development on military weapons and equipment.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Little Boy -- Code name for the gun-type weapon dropped on Hiroshima, Japan, August 6, 1945, during World War II. Originally called the Thin Man in reference to its long thin shape. The Thin Man was to use plutonium-239 as its nuclear material. Early samples of this isotope revealed that it contained small amounts of plutonium-240 which had a high preinitiation rate. A decision was then made to use uranium-235, allowing the length of the weapon to be radically reduced (due to the lower speed of assembly of the critical material). This change in outer shape was given the code name of Little Boy.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico. Called the Los Alamos Laboratory during World War II.

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Manhattan Engineer District -- A District of the Army Engineers established in August 1942 to provide the facilities that would be needed for design and construction of the atomic bomb.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

A En r v t Man n t l E

s A i ro e o o y s I

Naval Ordnance Laboratory -- A portion of the Bureau of Ordnance devoted to design and test of Naval ordnance.

Neutron -- An uncharged particle of slightly greater mass than the proton.

Operation Crossroads -- See Crossroads.

Pitch -- Motion of the bomb as it falls through the air, such that the nose and tail alternately rise and fall.

Proton -- The nucleus of the atom of the light isotope of hydrogen. It has a unit positive charge of electricity.

Prototype -- An early weapon type, generally hand-produced before a production run.

Pylon -- A strut to hold bomb in position below an airplane wing.

Pyrotechnic Fuze -- A fuze that operates by burning or detonation of a small charge of explosive.

Radar -- Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Ricochet -- A glancing rebound of a missile when it strikes a target.

Safing -- Putting a weapon in condition such that it cannot fire.

Salton Sea Test Base -- Located on the site of a Naval Auxiliary Air Station on the shores of Salton Sea, California. One of the early sites for ballistic tests of atomic bombs.

Sandia Research and Development Board -- A joint Sandia-Military board formed March 2, 1948, at Sandia Base to provide local guidance on weapons design.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent of uranium-238; the rest is uranium-235.

Z Division -- A division of the Los Alamos Scientific Laboratory, elements of which moved to Sandia Base and became the nucleus of Sandia Laboratory and Corporation.

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(b)(1), (b)(3)

MK 33 (T-317)
8" SHELL
TOTAL WT. 249 LBS.

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Mk 33 Shell Cross-Section

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Mk 23 Shell

12/28/53	Military Liaison Committee forwards development requirement for 16-inch Navy projectile (Katie) to Division of Military Application.
11/1/54	Military characteristics proposed.
7/1/55	Military Liaison Committee approves military characteristics.
10/56	Mk 23 Shell stockpiled.

TX-32 Shell

5/5/54	Division of Military Application requests Santa Fe Operations Office to develop a 240-mm atomic shell.
6/18/54	Division of Military Application releases military characteristics for T332 Shell.
5/55	Project canceled in favor of XW-48 implosion program.

Mk 33 Shell

6-53	Army Ordnance authorizes development of T317 8-inch atomic projectile.
2/54	Development funds for project provided.
4/54	Program placed on crash basis.
2/55	Emergency capability production achieved.

History of Gun-Type Artillery-Fired Atomic Projectiles

Mk 9 Shell

The possibility of developing an artillery-delivered gun-type atomic device was discussed in late 1949 by Army Ordnance. This shell would be a defensive or offensive weapon against infantry masses concentrated in front of the sector through which a breakthrough was planned. It was hoped that a nuclear artillery shell, fuzed for air burst, could destroy the ability of these troops to stage an attack, or to defend the sector.

Possible delivery methods considered for such a weapon included railway rifles, guided missiles, aircraft, or artillery field pieces. Railway rifles, besides being almost obsolete, were ruled out due to heavy weight and relative immobility. Guided missiles capable of carrying atomic warheads were not as yet available. Bombing inaccuracy and difficulty in identifying battlefield targets made use of aircraft-delivered weapons unattractive.

It was felt, however, that artillery field pieces could be used, at least until suitable guided missiles became available. Army Ordnance had developed a mobile gun of 240-mm diameter (about 9-1/2 inches), weighing 90 tons, which was soon to be proof-fired, and a conference was held with Los Alamos Scientific Laboratory personnel November 10, 1949, at which use of this gun was advocated. The nuclear designers stated that a gun-type nuclear device would fit inside a 240-mm gun barrel, although concern was felt about the relatively inefficient usage of fissionable material in such an assembly.[1]

Another meeting was held on the same subject January 16-17, 1950. Increased Los Alamos interest in the project had developed, and Army Ordnance representatives discussed possible shell designs. One proposal was to develop a 240-mm-diameter shell, to fit the mobile gun, and another was to install a 280-mm barrel on the 240-mm mount, thus allowing the shell diameter to increase to about 11 inches.[2]

AFAP (Artillery-Fired Atomic Projectile), and Button (possibly because it was predicted that the shell could be delivered "right on the button").

The Ordnance Department proposed a set of military characteristics that were considered in a Button Committee meeting of August 11, 1950, and accepted on a preliminary basis.[9] The shell would weigh about 890 pounds and be fired with a muzzle velocity of 1700 feet per second from a 280-mm gun mounted on a 240-mm carriage.

(b)(1), (b)(3)

The shell would be able to withstand temperatures from -65°F to +160°F during storage and transportation, and operating-temperature limitations would be determined by the gun itself.[10]

(b)(1), (b)(3) A device would be designed to provide a surface burst, and it was hoped that this feature could be available concurrently with the time fuze.

The Button Coordination Committee was dissolved October 23, 1950, with Santa Fe Operations Office noting that the number and variety of weapons currently being developed necessitated the establishment of a uniform policy for assignment of responsibilities. Button was in full development but not yet scheduled for production, and Los Alamos and Sandia were requested to assume normal project responsibilities.[12] Subsequently, Sandia took over control of the nonnuclear phases of Button, and reassigned many of the design tasks to Army Ordnance.

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This

(b)(1), (b)(3)

However, subsequent design improvements, selection of high-quality component parts, and eventually, the use of three parallel fuzes, increased operational reliability to the point where timer fuzes were felt to be satisfactory.

Prototype shells were being fired by mid-1951, and demonstrated that nuclear assembly was taking place at the proper point in the trajectory.

(b)(1), (b)(3)

This created a maximum force of 3800 g's. The design of a lighter version with longer range was considered, but the higher stresses involved in this design caused later abandonment of this modification.

(b)(1), (b)(3)

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A proposed TX-9 status and characteristics report was prepared by the TX-G Committee. This noted that development of the TX-9 had been telescoped to such an extent that much of the testing would have to be conducted after the design had been released to production.

(b)(1), (b)(3)

Three independently operating mechanical time fuzes were located near the nose of the shell.

(b)(1), (b)(3)

The TX-G Committee met November 2, 1951, and noted that much TX-9 work remained to be done, including testing of the initiators, fuzes, and the conduct of a full-scale nuclear test; and that temperature limitations on both shell and gun were yet to be established. However, the stockpile date would not permit

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delaying design freeze. There had been no formal issuance of the military characteristics, but the Committee felt that the TX-9 design was adequate for operational use.[22] Design release was accordingly issued November 15, 1951.[23]

The Sandia Weapons Development Board, meeting January 16, 1952, recommended that the TX-9 be released "to" (rather than "for") production.[24] The choice of preposition indicated that the weapon, in some respects such as tests and drawings, was not at the normal stage of release for full production activity.[25] The weapon system was praised for its mobility, and it was noted that the gun could be emplaced in 15 minutes, and that the same length of time was required to assemble and fire the nuclear round.

(b)(1), (b)(3)

The Sandia Weapons Development Board, February 11, 1952, again recommended that the TX-9 be released to production,[26] and this was accepted by the Military Liaison Committee April 14, 1952.[27]

Initial deliveries of the TX-9 to stockpile were made in April 1952, right on schedule. Since the military characteristics had not been issued and the testing program was not completed, these units were temporarily designated as PM-9 or Pre-Mark, rather than by the more formal title of Mk 9 Mod 0.[28]

The military characteristics were officially released by the Military Liaison Committee July 18, 1952.[29]

(b)(1), (b)(3)

(b)(1), (b)(3)

The shell would be able to withstand 100-percent humidity and temperatures up to 90°F.[30]

Sandia recommended to Santa Fe Operations Office October 14, 1952, that the Mk 9 Mod 0 Shell be approved for operational suitability, training, and emergency use, based on examination of 12 early-production shells from Picatinny Arsenal. This proposal was accepted, and the first War Reserve-quality shells, the Mk 9 Mod 0-ZZ, were accepted for stockpiling in October 1952 (ZZ was the nuclear identification).[31]

(b)(1), (b)(3)

The controllable arming feature of the military characteristics was given attention. The TX-G Committee took this under consideration, but later noted that it would be difficult to develop and might degrade the reliability of the shell due to its complexity.[34] The Committee reported that modification to the Mk 9 Mod 0, to bring it in line with all the military characteristics, would require much design and testing, and suggested that this work be assigned to the Ordnance Corps. It was felt that the need for TX-G Committee direction was

declining, and that it could be replaced by an Ad Hoc Committee for each weapon. On December 15, 1952, the Atomic Energy Commission requested the Military Liaison Committee to transfer responsibility for nonnuclear components of the Mk 9 to the Army, but no action was taken.

The testing program required telemetering of internal events in the Mk 9 Shell, and this posed a difficult problem.

(b)(1), (b)(3)

Sandia had meanwhile concluded that a rugged and accurate telemetering system would be needed for rockets and guided missiles, and started to work on the problem.[36] This was a major undertaking, due to the 5000-g acceleration experienced by the shell. Additionally, the limited space available in the shell case demanded extreme circuit simplicity, and antenna design was severely restricted by the requirement that the external ballistic shape remain unchanged.

Both Army Ordnance and Sandia prepared designs of telemetering systems, and the results were evaluated in a TX-G Committee meeting September 18, 1952. The Ordnance system contained two channels with microsecond time resolution and four with millisecond time resolution. Sandia provided a dual system, each having five channels with microsecond and six with millisecond time resolution.

(b)(1), (b)(3)

The Picatinny system, being immediately available, was used for the first tests, and was later replaced by the Sandia system.[34]

The Sandia telemetering system was tested at Aberdeen in mid-December 1952. Results were generally satisfactory, but swampy terrain prohibited efficient location of telemetering receiving stations, and the range was too short for the maximum range of the Mk 9.[37] A proposal was made that the telemetering tests be conducted at the Nevada Test Site, but the location was later changed

to Ft. Sill, Oklahoma, home of The Artillery Center. These tests were held from January 19, 1954, to February 5, 1954, with 19 rounds being fired. Telemetering results were excellent, as was the performance of the Mk 9 Shell.[38]

A full-scale test of the Mk 9 had meanwhile been proposed, both to provide the Army with an operational test and to allow effects studies, both nuclear and military.[39] A decision was made in late 1952 to conduct this test in Operation Upshot-Knothole at the Nevada Test Site,[40] and the Mk 9 Mod 0-ZZ Shell was successfully tested in Shot Grable May 23, 1953.

Some study had been given to updating the stockpiled PM-9's to Mark status. However, it was felt that the PM-9 was entirely adequate, and that conversion was not required. Production of the Mk 9 was completed November 1953.

In April 1957, the Mk 9 was replaced in stockpile by the Mk 19 Shell. Mk 9 Shells, tools, and test and handling equipment were transferred to the Army for training and test purposes.

Mk 19 Shell

By late 1952 it was felt possible to reduce the weight of the Mk 9 Shell by about 200 pounds. This would produce a shell with the same (280-mm or 11-inch) diameter as the Mk 9, but with longer range and higher yield. The proposed atomic projectile would have the same weight as conventional high-explosive 280-mm shells, making it unnecessary to provide special spotting rounds, firing tables, or propellant charges. The Army Ordnance Corps authorized this new project March 1953, and the design of this Shell, called by the Army the T315 or Button II, became the first item of business for the Acorn Committee, which was established April 2, 1953, to centralize work on gun-type weapons.

(b)(1), (b)(3)

The Division of Military Application authorized development of this program, called the TX-19 Shell, April 28, 1953.[42]

(b)(1), (b)(3)

Sandia entered the program in June 1954, when the Atomic Energy Commission requested it to provide inflight telemetry for the projectile firing tests.[45] Sandia developed a system by which the internal nuclear events, such as assembly of the subcritical portions of the gun, were monitored.

(b)(1), (b)(3)

The Shell would be 53.62 inches long, about an inch shorter than the Mk 9. The sequence of operation would be identical to the Mk 9, and the two shells would be externally very similar.

(b)(1), (b)(3)

The Army withdrew the requirement for controllable arming. New mechanical fuzes were developed, which were more easily set than those in the Mk 9. Tests were made of an impact device, to determine whether it was safe enough for use, but it did not become available in time.

Stockpiling of the nonnuclear parts of the new weapon started in July 1955.[46] Operational suitability tests were conducted in August 1955, and the Mk 19 was declared satisfactory for field use.

(b)(1), (b)(3)

The increased launching stresses due to the lighter weight required some redesign and strengthening of parts of the ignition, fuzing and safing systems.

The nose fuze and the two internal fuzes of the Mk 19 had redesigned setting features. Settings on the internal fuzes were made with a closed-end ratchet wrench that allowed more rapid and accurate positioning. All fuzes were set in a clockwise direction, facing the nose of the shell, to prevent backlash on firing.[44]

Mk 23 Shell

The development requirements for a 16-inch atomic projectile were forwarded by the Military Liaison Committee to the Division of Military Application December 28, 1953. These called for the design of a shell to be fired from Naval 16-inch rifles and which would use Mk 19 nuclear components.[47] The project, known as Katie, would develop a shell that could be used for atomic support during amphibious operations.

A design-release date of December 31, 1954, was proposed, with stockpiling by July 1955. The task was a relatively straightforward one; that of adapting the features of the 280-mm T315 (Mk 19) Shell to a case whose external configuration was that of the Navy 16-inch HC Projectile Mk 13.

(b)(1), (b)(3)

Nomenclature of TX-23 was assigned by Sandia March 30, 1954, and was Sandia's only involvement with the project, other than the work being accomplished on the Mk 19, which was also applicable to the Mk 23.[48]

(b)(1), (b)(3)

It was hoped to provide contact cleanup, but on a not-to-delay basis.[50]

The military characteristics were approved by the Military Liaison Committee in mid-1955. The fuzing system would be rugged, reliable, and easily set or reset.

(b)(1), (b)(3)

The shell would function in a temperature range from 0°F to 125°F, and preparation for firing would require no more than 15 minutes.[52] These characteristics were reviewed without comment by Sandia August 15, 1955.[53]

The status of the Mk 23 was discussed in the December 12, 1956 meeting of the Special Weapons Development Board. The shell had a diameter of 16 inches, a length of 63.7 inches, and a weight of 1900 pounds

(b)(1), (b)(3)

The fuzing system contained three independent mechanical time fuzes in the nose of the projectile.

(b)(1), (b)(3)

The Mk 23 was stockpiled, and initial units delivered to the Fleet in October 1956.[54] These initial deliveries were made during the same period that the Navy retired the last 16-inch rifle from active use.

TX-32 Shell

The Division of Military Application, May 5, 1954, requested the Santa Fe Operations Office to develop a 240-mm (~~8.465~~ 9.45 inch) atomic shell, using the Mk 9 gun-type nuclear components. This design would provide a shell for the Army's 240-mm howitzer. Full-scale development activities were subsequently authorized by the Santa Fe Operations Office, subject to availability of funds and to orderly integration of the project into the Los Alamos program.[55]

The Military characteristics for a Shell, AE, 240-mm, T332, were released by the Division of Military Application June 18, 1954. The Army would manage the project, and the Atomic Energy Commission would furnish nuclear design and components.[56]

(b)(1), (b)(3)

The design was canceled in May 1955, in favor of an 8-inch implosion design, the XW-48, which had been proposed by the University of California Radiation Laboratory.[58]

The design was made available July 1955, for emergency capability use with the 8-inch howitzer M-2.

(b)(1), (b)(3)

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Glossary of Terms

(b)(1), (b)(3)

Field Command -- The local office of the Armed Forces Special Weapon Project, located on Sandia Base, Albuquerque, New Mexico.

g -- Force equal to one unit gravity.

Gun Committee -- A joint committee of Los Alamos Scientific Laboratory and Sandia members, established to guide the development of all gun-type weapons.

Gun-Type Design -- An atomic weapon based on the principle that a supercritical mass of nuclear material can be created by bringing together two subcritical masses of such material. In practice, this is accomplished by placing one of the subcritical masses at the end of a gun barrel and shooting the other subcritical mass into it.

Implosion -- The effect created when a sphere of high explosive is detonated on its exterior surface. The force of the shock wave is directed largely toward the center of the sphere.

Initiator -- A source of neutrons.

Joint Chiefs of Staff -- ~~an Army-Navy-Air Force group to~~ determine policy and to develop joint strategic objectives of the Armed Forces.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

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Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico.

Mk 8 Bomb -- A gun-type atomic bomb and warhead designed for target penetration.

Microsecond -- One millionth of a second.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

Millisecond -- One thousandth of a second.

Operation Buster-Jangle -- See Buster-Jangle.

Operation Upshot-Knothole -- See Upshot-Knothole.

Oralloy -- A code term for enriched uranium. The two initial letters stand for Oak Ridge (where Oralloy was first made in quantity) added to alloy from Tube Alloys, Ltd., applied to the British wartime atomic energy project.

Picatinny Arsenal -- An arsenal of the Army, responsible for design of nuclear weapons for the Army.

Prototype -- An early weapon type, generally hand-produced before a production run.

Proximity Fuze -- A fuze that detonates the weapon as soon as it comes within a certain specified distance of the ground or target.

Sandia Weapons Development Board -- A joint Sandia-Military board at Sandia Base to provide local guidance on weapons design.

Santa Fe Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with Sandia operations.

Special Weapons Development Board -- Change of name for the Sandia Weapons Development Board, effective May 14, 1952.

Spotter Shells -- Nonnuclear shells that contain the same weight of projectile and powder charge as the atomic Shell. Can be used for proper range determination before the nuclear shell is fired.

(b)(1), (b)(3)

University of California Radiation Laboratory -- A laboratory established at Livermore, California. Initially founded for work on thermonuclear designs.

Upshot-Knothole -- Tests of atomic devices, held at the Nevada Test Site. Series of 11 shots, starting March 17 and ending June 4, 1953.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent of uranium-238; the rest is uranium-235.

Yield -- ~~A means of measuring~~ The measure of the effect of a nuclear detonation ~~by comparing~~ compared to ~~TNT~~ the effect of an explosion of TNT. By definition one kiloton is 10^{12} ~~calories~~ calories.

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May 1967

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AEC ATOMIC WEAPON DATA
Sigma 3, 7
L-7

HISTORY OF GUN-TYPE BOMBS AND WARHEADS (W)

Mks 8, 10 and 11 (U) Title unclassified per susan stinchcomb 4/18/2002

SC-M-67-658

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Mk 8 Exterior View

THE TX-8 BOMB

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(b)(1), (b)(3)

LENGTH—116 IN
DIAMETER—14.5 IN.
WEIGHT—3150 LBS

Mk 8 Cross Section

12/8/50	TX-G Steering Committee appointed and holds initial meeting.
1/26/51	
	(b)(3)
3/15/51	
Early 1951	Externally carried TX-8 Bomb assigned nomenclature of TX-8 Prime.
10/51	TX-8 Prime program divided into two parts: TX-8-X1 (to cover carriage at subsonic speeds) and TX-8-X2 (a program to reduce drag in high-speed carriage).
11/51	Mk 8 Mod 0 achieves production.
1/52	Mk 8 Mod 0 enters stockpile.
4/1/52	
	(b)(3)
9/53	Mk 8 Bomb with Mk 8 Mod 1 Fuze (TX-8-X2) enters stockpile.
11/55	Mk 8 Mod 3 Bomb enters stockpile.
5/57	Mk 8 Bombs retired as Mk 11 enters stockpile.

Mk 8 Warhead

3/50	Gun-type warheads considered for missile application.
9/13/50	Santa Fe Operations Office requests that penetrating warheads be applied to guided missiles.
2/14/51	Santa Fe Operations Office authorizes design of XW-8/REGULUS.
1/18/52	XW-5/REGULUS program assigned priority over XW-8/REGULUS.
8/21/52	Field Command forwards proposed military characteristics for XW-8/REGULUS to Sandia.
9/24/53	Successful XW-8/REGULUS system test held.

8/54 Design of XW-8/REGULUS completed.

5/20/55 Program activity suspended.

TX-10 Weapon

5/6/48 Sandia Research and Development Board assigns priorities to weapon design projects.

1/21/49 Division of Military Application requests Bureau of Ordnance to study possible adaptation of Mk 8 as a light air-burst weapon.

4/22/49 Military Liaison Committee requests that study be restricted to a preliminary investigation.

3/8/50 Guided-missile symposium at Sandia Base proposes use of a light-weight gun-type device as a missile warhead.

7/6/50 Military Liaison Committee releases formal requirement for an air-burst, gun-type warhead.

8/9/50 Military Liaison Committee establishes formal requirement for a lightweight air-turst bomb.

8/17/50 Division of Military Application forwards characteristics for lightweight air-burst bombs.

9/6/50 Bureau of Ordnance, in reply to January 21, 1949 request of the Division of Military Application, offers to adapt the Mk 8 as a lightweight air-burst bomb.

10/3/50 Division of Military Application notifies Bureau of Ordnance that Sandia will develop the lightweight air-burst bomb.

10/18/50 Sandia Weapons Development Board discusses bomb and warhead applications. Santa Fe Operations Office subsequently authorizes deletion of warhead requirement. Bomb officially designated the TX-10.

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4/1/55 Mk 11 design released.

1/1/56 Early production units of Mk 11 (Mk 91 Mod 0) become available.

7/1/56 Mk 91 Mod 0 enters stockpile.

8/56

(b)(3)

History of Gun-Type Bombs and Warheads

Mk 8 Bomb

The gun method of assembling nuclear material, used in the wartime Little Boy design, was the first atomic weapon system to be devised, predating the establishment of the Los Alamos Laboratory. The method was nuclearly inefficient and was largely ignored for a time after the end of World War II, while interest centered on implosion techniques.

(b)(1), (b)(3)

At this time, the Los Alamos Scientific Laboratory was fully occupied in the above-mentioned study of improvements in implosion devices, and suggested that the task of developing a water-penetrating weapon (which probably would use gun techniques) could best be accomplished by a military group. No immediate action was taken on this suggestion, but the subject was briefly examined by the Z Division of Los Alamos in late 1946 and early 1947.

(b)(1), (b)(3)

The topic was subsequently discussed in a meeting of the Weapons Subcommittee of the AEC General Advisory Committee, and a decision made May 15, 1947 that consideration of a penetrating weapon be postponed.[4]

Meanwhile, however, the Military Liaison Committee had been discussing the general subject of subsurface atomic weapons. At the instigation of the Navy member, Rear Admiral William S. Parsons (who had armed the wartime gun-type Little Boy for

its historic drop on Hiroshima), Section ReM of the Navy's Bureau of Ordnance, prepared preliminary sketches of a penetrating gun device.

At about the same time, other groups were considering the same subject. The Joint Research and Development Board had established a Committee on Atomic Energy, and the subject of penetrating weapons was discussed in the October 2, 1947 meeting of this Committee. It was urged that serious consideration be given to the development of a gun-type device suitable for penetration use. Since the AEC weapon laboratories were already fully occupied with other high-priority work, the Committee recommended that the facilities of the Bureau of Ordnance be used.[5]

The Division of Military Application had also been considering the advisability of invoking the assistance of the military services in the development of penetrating weapons. Los Alamos had noted that gun systems were inherently inefficient, and expressed an opinion that the weapons laboratories should continue to concentrate on design of implosion devices.[6] Thus the Military Liaison Committee was requested to assign mechanical design of a gun-type penetration weapon to the Bureau of Ordnance.[7]

These several requests, all in the same vein, were presented for consideration to the Military Liaison Committee which, April 9, 1948, requested the Atomic Energy Commission to undertake development of a penetrating-type weapon, using the facilities of the Bureau of Ordnance.[8] This request was formally presented to the Bureau April 27, 1948, and accepted.[9] A code name of "Minnie" was initially assigned to the project, but was later found to have been used for a Bureau of Ships propulsion project and, in mid-July 1948, the name was changed to "LC" (a follow-on term to "LB," for the Little Boy), and which came to be commonly written as "Elsie."[10] That the Elsie program was considered a matter of some interest to the Military was indicated in a May 6, 1948 meeting of the Sandia Research and Development Board in which the project was assigned top priority, second only to the schedule for getting the Mk 4 Bomb into full-scale production.

The Bureau of Ordnance issued detailed work assignments. The Naval Ordnance Laboratory would be responsible for developing suitable pyrotechnic delay fuzes.

The Naval Ordnance Test Station would study external ballistics and design the tail. The Naval Powder Factory would investigate powder development. The Naval Ordnance Plant would handle much of the manufacturing and testing program, and when this location was subsequently closed, the work would be transferred to the Naval Proving Grounds and the Naval Gun Factory. Section ReM of the Bureau of Ordnance would provide overall design controls, including the task of guaranteeing survival of the nuclear assembly under impact conditions.

The development program would proceed in three overlapping phases. Feasibility and preliminary design studies would outline the most promising general design characteristics of the weapon, and these were scheduled for completion January 1, 1949. The second phase, covering experimental development and testing of prototype weapon design, would be completed a year later. The third phase, manufacture of prototype weapons, would be finished in another year, or January 1, 1951.

(b)(3)

The studies advanced rapidly and, by September 3, 1948, the Bureau of Ordnance could report that the design appeared feasible and that a weapon could probably be devised that would function satisfactorily after impact on water, and possibly after impact on hard surfaces which the weapon might encounter beneath the surface of the water.[11] It was initially felt that the fuze should be actuated at impact and have a delay of 1 to 2 minutes before bomb detonation, but it was later decided that a more reliable bomb would be created if the fuze action were initiated at time of release of the bomb from the carrying aircraft.

The diameter of the bomb would be about 14 inches and the weight would be about 3000 pounds, as compared to 28 inches and 8900 pounds for the Little Boy. These reductions were due to the more compact nuclear assembly and a decrease in the thickness of the bomb case. The shape would be roughly cylindrical, with a flat nose for good penetration characteristics, and the bomb would attain a maximum impact velocity of 1500 feet per second. The minimum release altitude would be 500 feet, to give the bomb enough time during its fall to assume proper entry attitude, and there would be no restriction on maximum release altitude. It was felt that three separate and independent fuzes should be used, to provide adequate relisbility. A meeting was held October 25 and 26, 1948, with Los Alamos assuming the task of developing impact-resistant initiators.[12]

An extensive series of tests was performed. The first group included 174 half-scale bombs of 6.25-inch diameter. These were fabricated in 49 different configurations, and were impacted against targets of steel and concrete at different angles, striking velocities, and missile temperatures ranging from -65°F to +165°F.

(b)(3)

Following the above, some 38 full-scale impact tests were conducted, to confirm the half-scale results. Interior ballistic tests were performed, to check the burning rate of various propellants and the behavior of the missile in the gun barrel. As fuze components became available, they were subjected to the shock produced by firing from a 14.25-inch-diameter railway gun.

Two series of wind-tunnel tests were held, one at the University of Minnesota to obtain aerodynamic coefficients of various tail configurations, and the other at the California Institute of Technology Cooperative Wind Tunnel to evaluate aerodynamic characteristics of five basic designs.

This paper was circulated for comment to Sandia and Los Alamos as well as the Military, and was subjected to a critical review.[23] The formal issue of the characteristics on November 10, 1950, however, retained the release speed requirement and noted that the bomb should function reliably when released at any altitude up to 50,000 feet and survive impacts on water, reinforced concrete, and--hopefully--thin steel plate.

(b)(3)

The November 22, 1950 meeting of the Sandia Weapons Development Board reviewed the overall gun-type weapons program, which now included the TX-9, TX-10, and TX-11, in addition to the TX-8. It was noted that the TX-8 was composed of three main parts: The nose, the tail, and the clamping ring which joined them. The bomb diameter had been fixed at 14.5 inches, its length at 116 inches, and its weight at 3260 pounds. The nose was a heavy forging with a blunt shape for water and ground entry, and contained the internal gun barrel, tamper, and projectile.

(b)(3)

A saddle on the external top of the bomb case contained switches and electrical connections to operate the primers.[25]

Sandia had proposed that an interlaboratory gun-type weapon coordination committee be established, similar in scope and authority to the TX-5 Steering Committee. Action was taken on this suggestion in late 1950, and the first meeting of this Gun Committee, with representation from Los Alamos and Sandia, was held December 8, 1950.[26] At this time, the TX-5 Steering Committee was renamed the TX-N Steering Committee to reflect its interest in all implosion weapons, and the new Gun Committee came to be known as the TX-G Steering Committee.

The first meeting of the TX-G Committee heard a report from Los Alamos concerning progress on design of an initiator for the TX-8. The initial design had been based on the device used in the Little Boy, and was then modified as design weaknesses were uncovered by the testing program. Some idea of the problems encountered were shown by the increasing impact requirements as the design progressed. The initial

assumption had been that the highest shock encountered in ground impact would be 7500 g's. This figure had progressively increased during design and was now 100,000 to 300,000 g's.

(b)(3)

Studies were meanwhile in progress on systems for nuclear safing.

(b)(3)

In early 1951 it was decided to identify the adaptation of the TX-8 for external carriage at subsonic speeds as the TX-8' (or TX-8 Prime) program. Plans were made to make only minor changes to the TX-8 and provide early, but only partial, satisfaction of the requirements for an externally carried TX-8. It was felt that, if this program could not be accomplished within a short time, it should be canceled in favor of the TX-11 Bomb, then being designed for external carriage on high-speed aircraft.

At this time, the AD4 and the F4U5 were the only carriers specified for the TX-8'. The AD4 was selected as the test aircraft, and Sandia issued a contract through the Bureau of Aeronautics to Douglas Aircraft Company to modify this aircraft for TX-8 carriage. Douglas designed a nose cap to reduce drag and help protect the TX-8' fuzing elements.

In late October 1951, the TX-8' program was divided into two parts; the TX-8-X1 and TX-8-X2. The X1 was the basic TX-8' program; the X2 was to provide a cleaner aerodynamic design and reduce the drag caused by the saddle. Inasmuch as 20 drops had already been made with the TX-8-X1, its compatibility and reliability were felt to have been proven, and attention was concentrated on the TX-8-X2 design.[33]

The T-28 saddle functions were replaced by a small box located in the aircraft fuselage. This allowed the use of a standard two-hook bomb rack and increased the clearance between the externally carried bomb and the ground. Fairings were installed over the side fuzes to reduce drag. Fuze tapes used for safing were pulled through the nose fairing to protect them from the windstream. A quick disconnect was installed, to permit the weapon to be dropped with tapes in place, thus leaving barriers in the path between the primer and the propellant, and preventing the fuzes from firing the main propellant charge.

This new device was called the T-31, and a subcontract was issued for its development. Due to the subsequent failure of the subcontractor to achieve a satisfactory T-31, Sandia produced a design having the T-31 located inside the bomb pylon, thus making it possible to detach the arming tapes from the pylon after bomb release, and prevent aircraft damage caused by whipping of the tapes in the slipstream. This work was undertaken November 5, 1951, and satisfactory hardware was being produced 10 days later.

The Mk 8 Mod 0 weapon was initially produced in November 1951 and was stockpiled in January 1952.

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The Military Liaison Committee, in a letter dated October 20, 1952, requested that the bomb be designed to withstand storage for 6-month periods under occasional temperature extremes of -80°F to +165°F, and flight bomb-bay temperatures of -90°F. It was pointed out that external bomb carriage might experience even more rigorous conditions of -100°F during a 12-hour flight, and that the 24-hour limitation regarding weapon assembly would be operationally troublesome.[40]

Inasmuch as the propellant characteristics were specified by the Bureau of Ordnance, the problem was referred to this organization.[41] It was noted that the environmental criteria had been specified after detail design of the Mk 8 had been essentially completed, and that these criteria differed considerably from the initial Mk 8 development objectives. It was also pointed out that any project to provide a propellant with improved temperature characteristics would duplicate work being undertaken in the TX-11 program. The Bureau of Ordnance subsequently allowed relaxation of the temperature limitations to 7 days at 130°F, 60 days at 120°F, and indefinitely at 110°F.[42] On March 12, 1953, the Military Liaison Committee agreed that major redesign efforts toward relieving temperature limits be directed toward the TX-11.[43]

The possibility of water leakage into the interior of the gun nuclear system had been a matter of early concern.

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When recovered, there was only about half a cup of water in the barrel, and this leakage was not felt great. Nevertheless, the Military, in the April 16, 1952 meeting of the Sandia Weapons Development Board, requested that the possible effects of this leakage on weapon performance be studied.[38]

Consequently, drops were made on a limestone bed in southwestern New Mexico. This rock possessed extremely high compressive strengths, from 18,000 to 23,000 pounds per square inch (average concrete strengths were about 4500 psi).

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Only one weapon showed any evidence of leakage. Experiments were started, using O-rings as replacements for the cork gaskets used to seal the openings in the bomb case.

It had been decided that the TX-8-X2 changes constituted a modification to the fuze rather than the bomb. Thus the Mk 8 Bomb with Mk 8 Mod 1 Fuze, incorporating a frangible nose and T-31 fuze tape control, was released for production and entered stockpile September 1953.

The TX-G Committee, whose functions had been largely assumed by the Special Weapons Development Board, was dissolved in January 1954. The Aspen Committee, which was directing Sandia-Los Alamos activities on the TX-11 weapon, agreed to handle any residual interlaboratory matters on the Mk 8 program.

(b)(3)

This change was made in the Mk 8 Mod 2 Bomb which was stockpiled in May 1955.

Meanwhile, studies had been made of the desirability of replacing the original Abner initiator with an improved design, the Phoebe. This change, plus the O-rings for sealing the bomb case, was known as the TX-8-X3 program during development.[44] Changes to the Atomic Energy Act permitted the Military to produce and stockpile certain atomic weapons parts, and it was suggested that the Bureau of Ordnance assume control of TX-8-X3 production work.[45] This proposal was rejected by the Atomic Energy Commission, which felt that close phasing was required, due to changes to both nuclear and nonnuclear portions of the Mk 8, and that Sandia should retain production control.[46] The Mk 8 Mod 3 was stockpiled in October 1955.

By February 1957, the Mk 11 Bomb was in production and entering stockpile. A decision was made to retire the Mk 8 weapons on a one-for-one basis as Mk 11's entered War Reserve. This retirement program started May 1957 and was completed 2 months later.

Mk 8 Warhead

The first consideration of a gun-type device for use with guided missiles was in a Los Alamos meeting of early March 1950, in which various missile programs were discussed.[47] Little immediate action was taken and, during the summer of that year,

attention was concentrated on developing the Elsie as a free-fall bomb to be released from aircraft. However, September 13, 1950, Santa Fe Operations Office requested Sandia and Los Alamos to consider the application of a penetrating warhead to various guided missiles. The missiles suggested were the HERMES A-3, HERMES C-1, REGULUS, RIGEL, and TRITON.[48]

It was obvious that a gun-type warhead would be more impact-resistant than an implosion design, and the request was referred to the Bureau of Ordnance, then doing work on the Mk 8 Bomb.

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Any missile usage would involve higher impact velocities and require new tests and additional design effort.[49] The Division of Military Application then referred the project to the Sandia Weapons Development Board, requesting that any Mk 8 Warhead developed be compatible with the above five missiles.[50]

Sandia made a preliminary study and, December 20, 1950, reported to the Santa Fe Operations Office that a firm estimate of the magnitude of the program could not be made. The terminal velocities of the missiles cited had not been definitely fixed, but were believed to be significantly greater than any previously considered in atomic-bomb design. Sandia proposed that a general investigation of impact warheads be continued, in an effort to delineate the most universally useful type of warhead and to outline a development program.[51]

The Santa Fe Operations Office suggested that initial application of the penetrating warhead be made to the REGULUS missile. This missile, scheduled for production in 1953, had a comparatively low impact velocity, and it was felt that a suitable warhead might be created by relatively simple modifications of existing components.[52] Sandia reported, January 23, 1951, that the development of such a warhead appeared feasible, and that the Bureau of Ordnance had been requested to investigate the effects of impact velocities and warhead mounting methods on the penetration characteristics of the Mk 8 device.[53]

The XW-8/REGULUS was authorized for design activity by the Santa Fe Operations Office February 14, 1951.[54] It was noted that since the REGULUS would attain an

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impact velocity of only Mach 1.2, there would be few shock problems, unless the weapon were employed against extremely hard targets such as igneous rock or heavy armor plate.[55]

It was determined that the fuzing accuracy for the XW-8/REGULUS could be less than for an air-burst device, since the only requirement was to initiate a pyrotechnic delay train about one minute prior to impact. Should the weapon be launched from a submarine, a simple arming system would protect the submarine against premature detonations.

The Sandia Weapons Development Board discussed the Mk 8 missile-warhead program in its April 10, 1951 meeting. It was felt that current weapon capabilities would not allow impact velocities higher than Mach 2.5 without danger of breakup of the device. Since the terminal velocity of the HERMES was estimated to be Mach 4.5, it was obvious that radical changes to either warhead or missile would have to be made if this missile were used. It was apparent that either approach would require much design investigation, and it was decided to consider only the XW-8/REGULUS.[56]

It was found that the warhead compartment of the REGULUS was long enough to hold the basic Mk 8 Bomb assembly, but that little excess clearance was available, and that access to the nose of the weapon was difficult. Additionally, the center of gravity of the missile would be about 30 inches forward of its optimum location, and it was decided to delete the afterbody of the Mk 8. Tests were started to determine the terraballistics of the Mk 8 without its afterbody, and to ascertain whether the warhead would break away from the missile on impact with various surfaces.[57]

Another problem was the development of a mechanism to ignite the propellant of the internal gun device of the XW-8/REGULUS. In the drop bomb, this was accomplished by arming tapes, but the warhead application required either a device to pull the tapes at the proper point in the missile trajectory or a modification of the fuze.

yield would be the same as that of the Mk 8 Bomb. The warhead would function properly when subjected to missile impact speeds up to Mach 1.1 on water, earth, reinforced concrete and, if possible, harder targets. It would not broach or ricochet after impacts at angles between 60 and 90 degrees. The weapon would penetrate the target and detonate after coming to rest, and would be sufficiently watertight to function after water impact, followed by bottom impact.[64]

The Military Liaison Committee notified the Division of Military Application, October 3, 1952, that no requirement existed for design of penetration warheads capable of impact velocities higher than those of the REGULUS missile.[65]

Meanwhile, the Military decided that efficient use of the XW-8/REGULUS weapon required a high delivery accuracy. This was not possible with the existing missile system, and production requirements were deferred, awaiting refinement of the missile guidance system. Sandia was requested to complete its design work on the warhead, and the Navy was asked to proceed with scheduled flight tests.[66]

Successful component evaluation flights were conducted, and a successful warhead system test was held September 24, 1953. The Military Liaison Committee then suggested that, since there were few differences between the XW-8 Warhead and the extensively tested Mk 8 Bomb, further systems tests be held in abeyance.[67]

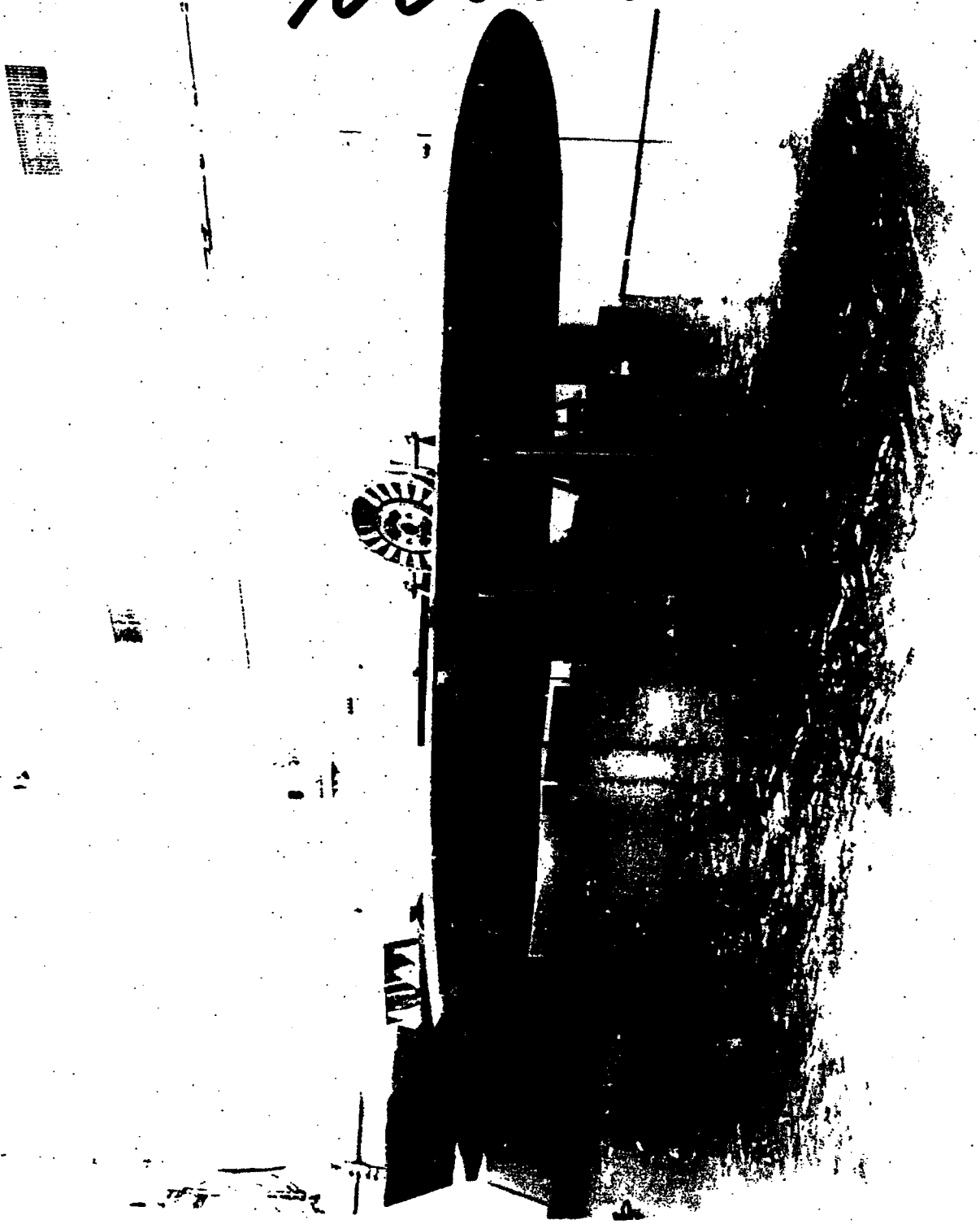
Design of the missile-warhead was completed in August 1954, and Report SC3483(TR), Status and Evaluation of the XW-8/REGULUS Warhead Installation at Design Release, was presented to the December 1, 1954 meeting of the Special Weapons Development Board.[68] The warhead was named the Mk 8 Mod 2, and production responsibility assigned to the Bureau of Ordnance.

The warhead contained three delay fuzes, two located on the side and one on the nose. (b)(3)

All requirements of the military characteristics were satisfied by the test program, although impact tests at less than 90 degrees were not conducted, and it was

not definitely determined whether the warhead would penetrate the target or break away on impact. However, Mk 8 Bomb tests had shown that satisfactory penetrations were achieved at entry angles as low as 30 degrees to the surface, and it was felt that the warhead would have similar satisfactory characteristics.

Subsequently, the possibility of developing a guidance system to effectively deliver the XW-8/REGULUS with pinpoint accuracy appeared remote. Consequently, on May 20, 1955, the Navy suspended activity in the program, together with work on the XW-11/REGULUS application.[69]



TX-10 External View

Subsequently, the Division of Military Application proposed that a lightweight, air-burst, gun-type missile warhead be developed,[74] and this suggestion received the backing of the Military Liaison Committee July 6, 1950.[75] It was proposed that Army Ordnance, then involved with the Mk 9 Shell, be requested to assist in design and development.[76]

Meanwhile, the lightweight, air-burst, gun-type bomb project had not been entirely forgotten, and the Military Liaison Committee, in a letter dated August 9, 1950, stated that the Joint Chiefs of Staff had established a requirement for the development of air-burst bombs sufficiently light in weight and small in cross section to be carried by high-speed tactical airplanes of the Air Force and Navy. It was felt that these bombs could be based on either implosion- or gun-type nuclear devices, and formal requests were made for both types.[77]

The subject was discussed in the August 16, 1950 meeting of the Sandia Weapons Development Board, with the Board agreeing to assume cognizance of the project. Two problems were immediately apparent: The development of a flexible fuzing system capable of attacking various tactical targets, and a weapon resistant to temperatures as low as -100°F.[78]

Sandia had meanwhile made a study of a lightweight bomb design and reported to AEC-Sandia August 17, 1950, that this could be produced by mid-1952. It was suggested that North American Aviation, Inc., be assigned the task of developing and manufacturing the outer case, internal support structures, and parts of the carrying pylon. Sandia would develop a fuzing and firing system, conduct drop tests, provide test and handling equipment, and act as project coordinator.[79]

On the same date, the Division of Military Application forwarded military characteristics for the above bomb. These required that the bomb be capable of tactical use by fighter, light bombardment, and attack (dive bomber) aircraft. The primary requirement was for external carriage, with alternate internal carriage being desired.

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The TX-G or Gun Committee agreed to accept interlaboratory responsibility for the TX-10.[26] The program was subjected to an intensive review in a Committee meeting of December 14, 1950, with the TX-10 being compared with the TX-7, an implosion design that had been pushed rapidly and which was now scheduled to enter stockpile earlier than the TX-10. It was felt by some conferees that the basic need for the TX-10 was eliminated by the advent of the TX-7. This latter weapon was larger than the proposed diameter of the TX-10 (27 inches versus 17 inches), but there appeared to be a sufficient variety of airplanes that could carry the TX-7.

(b)(1), (b)(3)

The problem was referred to the Sandia Weapons Development Board and discussed in a meeting December 20, 1950, with the Board being furnished copies of Sandia Report SC-1684(TR), A Critical Comparison Between the TX-7 and TX-10 Programs. This report noted that design was in work on a follow-on (and smaller) implosion device for the TX-7 (to be called the TX-12). The TX-12 would be less costly from the nuclear standpoint, would offer greater chances of increasing nuclear efficiency, and could be developed in about the same time scales. It was pointed out that work on the TX-10 would subtract effort from the TX-12, and that tactical use of the TX-10 (if manufactured in large numbers) would require major realignment of component production.

The Board noted that the TX-10 diameter would probably be smaller than the TX-7 or TX-12, but stated that further reductions in implosion-weapon diameter could be expected, as much nuclear design effort was currently being placed on implosion design improvements. After extensive discussion, the Board recommended that the TX-10 development be dropped in favor of the TX-12.[89]

The Division of Military Application wrote to Santa Fe Operations Office January 3, 1951, making reference to the above meeting. There were hopes that an interim TX-10 could be made available earlier than the TX-12, and it was suggested that the requirement for nuclear safing be eliminated and an external shape suitable for subsonic (but not necessarily supersonic) carriage be provided.[90]

The design status of the TX-10 was reviewed in the April 10, 1951 meeting of the Sandia Weapons Development Board. The bomb would be at least 17 inches in diameter and 2000 pounds in weight.

(b)(3), (b)(1)

The Board noted that the diameter and weight of the TX-10 exceeded the military characteristics, and that major reductions in these items could not be expected until the nuclear gun design was revised by Los Alamos.

(b)(3)

The project thus reverted to fundamental study of the problems of providing low burst heights, miniaturization, supersonic aerodynamics, and nuclear design improvements. Subsequently, the Military Liaison Committee canceled the TX-10 Bomb program May 7, 1952, noting that the Joint Chiefs of Staff had stated that a military requirement for the weapon no longer existed.

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Mk 11 Weapon

The Mk 11 Bomb, a gun-type penetrating weapon to be externally carried on high-speed aircraft, had its early beginnings when the gun-type device was considered for guided-missile application in March 1950. In this usage nuclear safing would be required to protect the missile launching site, and it would be necessary for the warhead to survive high impact velocities.[47]

Subsequently, the Division of Military Application expressed interest in a gun-type bomb that could be nuclearly safed and externally carried on high-speed aircraft.[99] The external shape of the Mk 8 did not lend itself to such carriage (due chiefly to its blunt nose), and it was felt that any modification of the nose shape would be complicated by the existence of the nose fuze. A nose redesign would require a lengthy effort, and it was suggested that a development program be authorized for a Mk II Elsie for such usage.[100]

The Military Liaison Committee released a set of desired military and technical characteristics for impact, delayed-action atomic bombs April 17, 1950. These characteristics described a bomb which could be nuclearly safed during aircraft carriage and that would be suitable for release at speeds up to Mach 1.2.[54] Subsequently, July 31, 1950, the Division of Military Application requested the Bureau of Ordnance to design a Mk 8-type weapon meeting these characteristics, and offered Sandia assistance in the task of fitting the design to appropriate carrying aircraft.[101] This proposal was accepted by the Bureau of Ordnance,[102] and nomenclature of TX-11 was assigned to the project November 29, 1950.[103]

There were three main gun-weapon problems being studied at this time: The ballistics problem relating to external carriage and release at high speeds; the nuclear safing problem, which concerned missiles as well as bombs; and the problem of increasing the resistance of the weapon to impacts on hard targets, such as reinforced concrete, rock and armor plate.

The Naval Ordnance Laboratory started to design the TX-11 fuzing system. It was felt that feasibility and preliminary design studies to establish tentative characteristics could be completed by January 1, 1952; and that detailed design

toss, glide and dive bombing. It would be capable of carriage and release at speeds up to Mach 1.4 and altitudes of 50,000 feet. It would be able to function satisfactorily after impacts on water, soil, reinforced concrete, and--to the extent practicable--harder targets.

The Board noted that the characteristics required external carriage at both subsonic and supersonic speeds, but a shape designed for one of these velocities would not be optimum for the other. It was felt that the design should be based on the assumption that the least drag during the major portion of the flight was desirable. Inasmuch as jet fighters en route to a target cruised at subsonic speeds, the bomb shape should be designed to meet this requirement.

The desire that the weapon be capable of penetration into hard rock was of concern. It was difficult to suitably define "hard rock," and there was felt to be a low incidence of this type of terrain near any probable targets. The scheduled design-release date was established as October 1953, with the bomb to enter stockpile in January 1955.[34]

The Bureau of Ordnance had been conducting tests of a soft-steel nose cap which, it was hoped, would crush and absorb the shock of weapon impact. These tests were not encouraging, and it was eventually decided to provide a Fiberglas nose cap. When the bomb was to be carried in an internal bomb bay, this nose cap could be removed.

Wind-tunnel tests had meanwhile narrowed the choice of weapon length to two possibilities; 146 and 169 inches. The Bureau of Ordnance recommended that the shorter figure be selected: It caused less drag at subsonic speed, it was compatible with all aircraft being considered for carriage of the bomb, and it could be carried internally in all aircraft except the B-50 without removing the nose cap.[109]

Full-scale drops at Inyokern produced excellent results.

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No detonation of the high explosive occurred during any of the impacts. Tests of 6-1/4-inch-diameter scale models against reinforced concrete 10 feet thick demonstrated that impact velocities between 2000 and 2200 feet per second could be

absorbed.[110] As a result of these tests, the length of the TX-11 was frozen at 146 inches on June 30, 1952, and the fin size was established at two bomb diameters, or 28 inches.[111]

Meanwhile, work had been undertaken on the design of a nuclear safing system,

(b)(3)

The fuzes were mechanically armed and were of a pyrotechnic design similar to those used in the Mk 8.

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Glossary of Terms

Ad Hoc Working Group -- A group established by the Guided Missiles Committee to oversee the design of one particular missile-warhead installation.

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions related to atomic weapons.

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Contact Fuze -- A fuze that detonates the weapon by contact with the ground or target.

Crossroads -- Full-scale tests of Mk III Bombs, held at the Pacific Proving Grounds. The Bikini Baker shot was held July 25, 1946. Much effects data were gained, and the shot was so destructive that a scheduled deep underwater burst was canceled.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

Drag -- Resistance created by the passage of a shape through the air.

Field Command -- The local office of the Armed Forces Special Weapons Project, located on Sandia Base, Albuquerque, New Mexico.

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Joint Research and Development Board -- A Board established in mid-1946 as a postwar replacement for the Office of Scientific Research and Development. Its purpose was to suggest lines of research and development on military weapons and equipment.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Little Boy -- Code name for the gun-type weapon dropped on Hiroshima, Japan, August 6, 1945, during World War II. Originally called the Thin Man in reference to its long thin shape. The Thin Man was to use plutonium-239 as its nuclear material. Early samples of this isotope revealed that it contained small amounts of plutonium-240 which had a high preinitiation rate. A decision was then made to use uranium-235, allowing the length of the weapon to be radically reduced (due to the lower speed of assembly of the critical material). This change in outer shape was given the code name of Little Boy.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico. Called the Los Alamos Laboratory during World War II.

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Manhattan Engineer District -- A District of the Army Engineers established in August 1942 to provide the facilities that would be needed for design and construction of the atomic bomb.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

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Naval Ordnance Laboratory -- A portion of the Bureau of Ordnance devoted to design and test of Naval ordnance.

Neutron -- An uncharged particle of slightly greater mass than the proton.

Operation Crossroads -- See Crossroads.

Pitch -- Motion of the bomb as it falls through the air, such that the nose and tail alternately rise and fall.

Proton -- The nucleus of the atom of the light isotope of hydrogen. It has a unit positive charge of electricity.

Prototype -- An early weapon type, generally hand-produced before a production run.

Pylon -- A strut to hold bomb in position below an airplane wing.

Pyrotechnic Fuze -- A fuze that operates by burning or detonation of a small charge of explosive.

Radar -- Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Ricochet -- A glancing rebound of a missile when it strikes a target.

Safing -- Putting a weapon in condition such that it cannot fire.

Salton Sea Test Base -- Located on the site of a Naval Auxiliary Air Station on the shores of Salton Sea, California. One of the early sites for ballistic tests of atomic bombs.

Sandia Research and Development Board -- A joint Sandia-Military board formed March 2, 1948, at Sandia Base to provide local guidance on weapons design.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent of uranium-238; the rest is uranium-235.

Z Division -- A division of the Los Alamos Scientific Laboratory, elements of which moved to Sandia Base and became the nucleus of Sandia Laboratory and Corporation.

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AEC ATOMIC WEAPON DATA
Sigma 3, 7
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HISTORY OF GUN-TYPE BOMBS AND WARHEADS (W)

Mks 8, 10 and 11 (U) Title unclassified per susan stinchcomb 4/18/2002

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Mk 8 Exterior View

THE TX-8 BOMB

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(b)(1), (b)(3)

LENGTH—116 IN
DIAMETER—14.5 IN.
WEIGHT—3150 LBS

Mk 8 Cross Section

12/8/50	TX-G Steering Committee appointed and holds initial meeting.
1/26/51	
	(b)(3)
3/15/51	
Early 1951	Externally carried TX-8 Bomb assigned nomenclature of TX-8 Prime.
10/51	TX-8 Prime program divided into two parts: TX-8-X1 (to cover carriage at subsonic speeds) and TX-8-X2 (a program to reduce drag in high-speed carriage).
11/51	Mk 8 Mod 0 achieves production.
1/52	Mk 8 Mod 0 enters stockpile.
4/1/52	
	(b)(3)
9/53	Mk 8 Bomb with Mk 8 Mod 1 Fuze (TX-8-X2) enters stockpile.
11/55	Mk 8 Mod 3 Bomb enters stockpile.
5/57	Mk 8 Bombs retired as Mk 11 enters stockpile.

Mk 8 Warhead

3/50	Gun-type warheads considered for missile application.
9/13/50	Santa Fe Operations Office requests that penetrating warheads be applied to guided missiles.
2/14/51	Santa Fe Operations Office authorizes design of XW-8/REGULUS.
1/18/52	XW-5/REGULUS program assigned priority over XW-8/REGULUS.
8/21/52	Field Command forwards proposed military characteristics for XW-8/REGULUS to Sandia.
9/24/53	Successful XW-8/REGULUS system test held.

8/54 Design of XW-8/REGULUS completed.

5/20/55 Program activity suspended.

TX-10 Weapon

5/6/48 Sandia Research and Development Board assigns priorities to weapon design projects.

1/21/49 Division of Military Application requests Bureau of Ordnance to study possible adaptation of Mk 8 as a light air-burst weapon.

4/22/49 Military Liaison Committee requests that study be restricted to a preliminary investigation.

3/8/50 Guided-missile symposium at Sandia Base proposes use of a light-weight gun-type device as a missile warhead.

7/6/50 Military Liaison Committee releases formal requirement for an air-burst, gun-type warhead.

8/9/50 Military Liaison Committee establishes formal requirement for a lightweight air-turst bomb.

8/17/50 Division of Military Application forwards characteristics for lightweight air-burst bombs.

9/6/50 Bureau of Ordnance, in reply to January 21, 1949 request of the Division of Military Application, offers to adapt the Mk 8 as a lightweight air-burst bomb.

10/3/50 Division of Military Application notifies Bureau of Ordnance that Sandia will develop the lightweight air-burst bomb.

10/18/50 Sandia Weapons Development Board discusses bomb and warhead applications. Santa Fe Operations Office subsequently authorizes deletion of warhead requirement. Bomb officially designated the TX-10.

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4/1/55 Mk 11 design released.

1/1/56 Early production units of Mk 11 (Mk 91 Mod 0) become available.

7/1/56 Mk 91 Mod 0 enters stockpile.

8/56

(b)(3)

History of Gun-Type Bombs and Warheads

Mk 8 Bomb

The gun method of assembling nuclear material, used in the wartime Little Boy design, was the first atomic weapon system to be devised, predating the establishment of the Los Alamos Laboratory. The method was nuclearly inefficient and was largely ignored for a time after the end of World War II, while interest centered on implosion techniques.

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At this time, the Los Alamos Scientific Laboratory was fully occupied in the above-mentioned study of improvements in implosion devices, and suggested that the task of developing a water-penetrating weapon (which probably would use gun techniques) could best be accomplished by a military group. No immediate action was taken on this suggestion, but the subject was briefly examined by the Z Division of Los Alamos in late 1946 and early 1947.

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The topic was subsequently discussed in a meeting of the Weapons Subcommittee of the AEC General Advisory Committee, and a decision made May 15, 1947 that consideration of a penetrating weapon be postponed.[4]

Meanwhile, however, the Military Liaison Committee had been discussing the general subject of subsurface atomic weapons. At the instigation of the Navy member, Rear Admiral William S. Parsons (who had armed the wartime gun-type Little Boy for

its historic drop on Hiroshima), Section ReM of the Navy's Bureau of Ordnance, prepared preliminary sketches of a penetrating gun device.

At about the same time, other groups were considering the same subject. The Joint Research and Development Board had established a Committee on Atomic Energy, and the subject of penetrating weapons was discussed in the October 2, 1947 meeting of this Committee. It was urged that serious consideration be given to the development of a gun-type device suitable for penetration use. Since the AEC weapon laboratories were already fully occupied with other high-priority work, the Committee recommended that the facilities of the Bureau of Ordnance be used.[5]

The Division of Military Application had also been considering the advisability of invoking the assistance of the military services in the development of penetrating weapons. Los Alamos had noted that gun systems were inherently inefficient, and expressed an opinion that the weapons laboratories should continue to concentrate on design of implosion devices.[6] Thus the Military Liaison Committee was requested to assign mechanical design of a gun-type penetration weapon to the Bureau of Ordnance.[7]

These several requests, all in the same vein, were presented for consideration to the Military Liaison Committee which, April 9, 1948, requested the Atomic Energy Commission to undertake development of a penetrating-type weapon, using the facilities of the Bureau of Ordnance.[8] This request was formally presented to the Bureau April 27, 1948, and accepted.[9] A code name of "Minnie" was initially assigned to the project, but was later found to have been used for a Bureau of Ships propulsion project and, in mid-July 1948, the name was changed to "LC" (a follow-on term to "LB," for the Little Boy), and which came to be commonly written as "Elsie."[10] That the Elsie program was considered a matter of some interest to the Military was indicated in a May 6, 1948 meeting of the Sandia Research and Development Board in which the project was assigned top priority, second only to the schedule for getting the Mk 4 Bomb into full-scale production.

The Bureau of Ordnance issued detailed work assignments. The Naval Ordnance Laboratory would be responsible for developing suitable pyrotechnic delay fuzes.

The Naval Ordnance Test Station would study external ballistics and design the tail. The Naval Powder Factory would investigate powder development. The Naval Ordnance Plant would handle much of the manufacturing and testing program, and when this location was subsequently closed, the work would be transferred to the Naval Proving Grounds and the Naval Gun Factory. Section ReM of the Bureau of Ordnance would provide overall design controls, including the task of guaranteeing survival of the nuclear assembly under impact conditions.

The development program would proceed in three overlapping phases. Feasibility and preliminary design studies would outline the most promising general design characteristics of the weapon, and these were scheduled for completion January 1, 1949. The second phase, covering experimental development and testing of prototype weapon design, would be completed a year later. The third phase, manufacture of prototype weapons, would be finished in another year, or January 1, 1951.

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The studies advanced rapidly and, by September 3, 1948, the Bureau of Ordnance could report that the design appeared feasible and that a weapon could probably be devised that would function satisfactorily after impact on water, and possibly after impact on hard surfaces which the weapon might encounter beneath the surface of the water.[11] It was initially felt that the fuze should be actuated at impact and have a delay of 1 to 2 minutes before bomb detonation, but it was later decided that a more reliable bomb would be created if the fuze action were initiated at time of release of the bomb from the carrying aircraft.

The diameter of the bomb would be about 14 inches and the weight would be about 3000 pounds, as compared to 28 inches and 8900 pounds for the Little Boy. These reductions were due to the more compact nuclear assembly and a decrease in the thickness of the bomb case. The shape would be roughly cylindrical, with a flat nose for good penetration characteristics, and the bomb would attain a maximum impact velocity of 1500 feet per second. The minimum release altitude would be 500 feet, to give the bomb enough time during its fall to assume proper entry attitude, and there would be no restriction on maximum release altitude. It was felt that three separate and independent fuzes should be used, to provide adequate relisbility. A meeting was held October 25 and 26, 1948, with Los Alamos assuming the task of developing impact-resistant initiators.[12]

An extensive series of tests was performed. The first group included 174 half-scale bombs of 6.25-inch diameter. These were fabricated in 49 different configurations, and were impacted against targets of steel and concrete at different angles, striking velocities, and missile temperatures ranging from -65°F to +165°F.

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Following the above, some 38 full-scale impact tests were conducted, to confirm the half-scale results. Interior ballistic tests were performed, to check the burning rate of various propellants and the behavior of the missile in the gun barrel. As fuze components became available, they were subjected to the shock produced by firing from a 14.25-inch-diameter railway gun.

Two series of wind-tunnel tests were held, one at the University of Minnesota to obtain aerodynamic coefficients of various tail configurations, and the other at the California Institute of Technology Cooperative Wind Tunnel to evaluate aerodynamic characteristics of five basic designs.

directive was issued August 30, 1950, accompanied by a request that the facilities of the Bureau of Ordnance be used to the fullest extent possible.[17] At this time, the Elsie was assigned nomenclature of TX-8.[18]

An intensive study had been undertaken of changes required to allow external carriage of the TX-8. There were several reasons why these changes were necessary. For one, the fuze system had been designed to operate under protected bomb-bay conditions. For another, the shape of the TX-8, with its blunt nose, caused excessive drag, especially at high speeds.

(b)(3)

It was obvious that this would require considerable study, and it was suggested that the Bureau of Ordnance establish a parallel program for the development of a Mk II Elsie suitable for either internal or external suspension, while work continued on an internally carried TX-8.[19]

The Bureau made a survey and reported that the existing shape of the TX-8 was adequate for subsonic external carriage if some minor changes were made to the tail design,[20] and the shape could be carried in the space available under the centerline of the F4U, AD and A2D airplanes. It was noted that development of a shape for external carriage at supersonic velocities would require additional study and development, and this effort would be of interest in connection with a recent proposal that an XW-8 Warhead be fitted to a guided missile. Subsequently, October 3, 1950, the Division of Military Application authorized development of an externally carried TX-8 with subsonic aircraft and development of a new bomb (the TX-11) for high-speed external carriage.[21]

Meanwhile, the Armed Forces Special Weapons Project had been drawing up a paper specifying the desired military and technical characteristics of penetrating-type weapons.

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This paper was circulated for comment to Sandia and Los Alamos as well as the Military, and was subjected to a critical review.[23] The formal issue of the characteristics on November 10, 1950, however, retained the release speed requirement and noted that the bomb should function reliably when released at any altitude up to 50,000 feet and survive impacts on water, reinforced concrete, and--hopefully--thin steel plate.

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The November 22, 1950 meeting of the Sandia Weapons Development Board reviewed the overall gun-type weapons program, which now included the TX-9, TX-10, and TX-11, in addition to the TX-8. It was noted that the TX-8 was composed of three main parts: The nose, the tail, and the clamping ring which joined them. The bomb diameter had been fixed at 14.5 inches, its length at 116 inches, and its weight at 3260 pounds. The nose was a heavy forging with a blunt shape for water and ground entry, and contained the internal gun barrel, tamper, and projectile.

(b)(3)

A saddle on the external top of the bomb case contained switches and electrical connections to operate the primers.[25]

Sandia had proposed that an interlaboratory gun-type weapon coordination committee be established, similar in scope and authority to the TX-5 Steering Committee. Action was taken on this suggestion in late 1950, and the first meeting of this Gun Committee, with representation from Los Alamos and Sandia, was held December 8, 1950.[26] At this time, the TX-5 Steering Committee was renamed the TX-N Steering Committee to reflect its interest in all implosion weapons, and the new Gun Committee came to be known as the TX-G Steering Committee.

The first meeting of the TX-G Committee heard a report from Los Alamos concerning progress on design of an initiator for the TX-8. The initial design had been based on the device used in the Little Boy, and was then modified as design weaknesses were uncovered by the testing program. Some idea of the problems encountered were shown by the increasing impact requirements as the design progressed. The initial

assumption had been that the highest shock encountered in ground impact would be 7500 g's. This figure had progressively increased during design and was now 100,000 to 300,000 g's.

(b)(3)

Studies were meanwhile in progress on systems for nuclear safing.

(b)(3)

In early 1951 it was decided to identify the adaptation of the TX-8 for external carriage at subsonic speeds as the TX-8' (or TX-8 Prime) program. Plans were made to make only minor changes to the TX-8 and provide early, but only partial, satisfaction of the requirements for an externally carried TX-8. It was felt that, if this program could not be accomplished within a short time, it should be canceled in favor of the TX-11 Bomb, then being designed for external carriage on high-speed aircraft.

At this time, the AD4 and the F4U5 were the only carriers specified for the TX-8'. The AD4 was selected as the test aircraft, and Sandia issued a contract through the Bureau of Aeronautics to Douglas Aircraft Company to modify this aircraft for TX-8 carriage. Douglas designed a nose cap to reduce drag and help protect the TX-8' fuzing elements.

In late October 1951, the TX-8' program was divided into two parts; the TX-8-X1 and TX-8-X2. The X1 was the basic TX-8' program; the X2 was to provide a cleaner aerodynamic design and reduce the drag caused by the saddle. Inasmuch as 20 drops had already been made with the TX-8-X1, its compatibility and reliability were felt to have been proven, and attention was concentrated on the TX-8-X2 design.[33]

The T-28 saddle functions were replaced by a small box located in the aircraft fuselage. This allowed the use of a standard two-hook bomb rack and increased the clearance between the externally carried bomb and the ground. Fairings were installed over the side fuzes to reduce drag. Fuze tapes used for safing were pulled through the nose fairing to protect them from the windstream. A quick disconnect was installed, to permit the weapon to be dropped with tapes in place, thus leaving barriers in the path between the primer and the propellant, and preventing the fuzes from firing the main propellant charge.

This new device was called the T-31, and a subcontract was issued for its development. Due to the subsequent failure of the subcontractor to achieve a satisfactory T-31, Sandia produced a design having the T-31 located inside the bomb pylon, thus making it possible to detach the arming tapes from the pylon after bomb release, and prevent aircraft damage caused by whipping of the tapes in the slipstream. This work was undertaken November 5, 1951, and satisfactory hardware was being produced 10 days later.

The Mk 8 Mod 0 weapon was initially produced in November 1951 and was stockpiled in January 1952.

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The Military Liaison Committee, in a letter dated October 20, 1952, requested that the bomb be designed to withstand storage for 6-month periods under occasional temperature extremes of -80°F to +165°F, and flight bomb-bay temperatures of -90°F. It was pointed out that external bomb carriage might experience even more rigorous conditions of -100°F during a 12-hour flight, and that the 24-hour limitation regarding weapon assembly would be operationally troublesome.[40]

Inasmuch as the propellant characteristics were specified by the Bureau of Ordnance, the problem was referred to this organization.[41] It was noted that the environmental criteria had been specified after detail design of the Mk 8 had been essentially completed, and that these criteria differed considerably from the initial Mk 8 development objectives. It was also pointed out that any project to provide a propellant with improved temperature characteristics would duplicate work being undertaken in the TX-11 program. The Bureau of Ordnance subsequently allowed relaxation of the temperature limitations to 7 days at 130°F, 60 days at 120°F, and indefinitely at 110°F.[42] On March 12, 1953, the Military Liaison Committee agreed that major redesign efforts toward relieving temperature limits be directed toward the TX-11.[43]

The possibility of water leakage into the interior of the gun nuclear system had been a matter of early concern.

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When recovered, there was only about half a cup of water in the barrel, and this leakage was not felt great. Nevertheless, the Military, in the April 16, 1952 meeting of the Sandia Weapons Development Board, requested that the possible effects of this leakage on weapon performance be studied.[38]

Consequently, drops were made on a limestone bed in southwestern New Mexico. This rock possessed extremely high compressive strengths, from 18,000 to 23,000 pounds per square inch (average concrete strengths were about 4500 psi).

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Only one weapon showed any evidence of leakage. Experiments were started, using O-rings as replacements for the cork gaskets used to seal the openings in the bomb case.

It had been decided that the TX-8-X2 changes constituted a modification to the fuze rather than the bomb. Thus the Mk 8 Bomb with Mk 8 Mod 1 Fuze, incorporating a frangible nose and T-31 fuze tape control, was released for production and entered stockpile September 1953.

The TX-G Committee, whose functions had been largely assumed by the Special Weapons Development Board, was dissolved in January 1954. The Aspen Committee, which was directing Sandia-Los Alamos activities on the TX-11 weapon, agreed to handle any residual interlaboratory matters on the Mk 8 program.

(b)(3)

This change was made in the Mk 8 Mod 2 Bomb which was stockpiled in May 1955.

Meanwhile, studies had been made of the desirability of replacing the original Abner initiator with an improved design, the Phoebe. This change, plus the O-rings for sealing the bomb case, was known as the TX-8-X3 program during development.[44] Changes to the Atomic Energy Act permitted the Military to produce and stockpile certain atomic weapons parts, and it was suggested that the Bureau of Ordnance assume control of TX-8-X3 production work.[45] This proposal was rejected by the Atomic Energy Commission, which felt that close phasing was required, due to changes to both nuclear and nonnuclear portions of the Mk 8, and that Sandia should retain production control.[46] The Mk 8 Mod 3 was stockpiled in October 1955.

By February 1957, the Mk 11 Bomb was in production and entering stockpile. A decision was made to retire the Mk 8 weapons on a one-for-one basis as Mk 11's entered War Reserve. This retirement program started May 1957 and was completed 2 months later.

Mk 8 Warhead

The first consideration of a gun-type device for use with guided missiles was in a Los Alamos meeting of early March 1950, in which various missile programs were discussed.[47] Little immediate action was taken and, during the summer of that year,

attention was concentrated on developing the Elsie as a free-fall bomb to be released from aircraft. However, September 13, 1950, Santa Fe Operations Office requested Sandia and Los Alamos to consider the application of a penetrating warhead to various guided missiles. The missiles suggested were the HERMES A-3, HERMES C-1, REGULUS, RIGEL, and TRITON.[48]

It was obvious that a gun-type warhead would be more impact-resistant than an implosion design, and the request was referred to the Bureau of Ordnance, then doing work on the Mk 8 Bomb.

(b)(1), (b)(3)

Any missile usage would involve higher impact velocities and require new tests and additional design effort.[49] The Division of Military Application then referred the project to the Sandia Weapons Development Board, requesting that any Mk 8 Warhead developed be compatible with the above five missiles.[50]

Sandia made a preliminary study and, December 20, 1950, reported to the Santa Fe Operations Office that a firm estimate of the magnitude of the program could not be made. The terminal velocities of the missiles cited had not been definitely fixed, but were believed to be significantly greater than any previously considered in atomic-bomb design. Sandia proposed that a general investigation of impact warheads be continued, in an effort to delineate the most universally useful type of warhead and to outline a development program.[51]

The Santa Fe Operations Office suggested that initial application of the penetrating warhead be made to the REGULUS missile. This missile, scheduled for production in 1953, had a comparatively low impact velocity, and it was felt that a suitable warhead might be created by relatively simple modifications of existing components.[52] Sandia reported, January 23, 1951, that the development of such a warhead appeared feasible, and that the Bureau of Ordnance had been requested to investigate the effects of impact velocities and warhead mounting methods on the penetration characteristics of the Mk 8 device.[53]

The XW-8/REGULUS was authorized for design activity by the Santa Fe Operations Office February 14, 1951.[54] It was noted that since the REGULUS would attain an

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impact velocity of only Mach 1.2, there would be few shock problems, unless the weapon were employed against extremely hard targets such as igneous rock or heavy armor plate.[55]

It was determined that the fuzing accuracy for the XW-8/REGULUS could be less than for an air-burst device, since the only requirement was to initiate a pyrotechnic delay train about one minute prior to impact. Should the weapon be launched from a submarine, a simple arming system would protect the submarine against premature detonations.

The Sandia Weapons Development Board discussed the Mk 8 missile-warhead program in its April 10, 1951 meeting. It was felt that current weapon capabilities would not allow impact velocities higher than Mach 2.5 without danger of breakup of the device. Since the terminal velocity of the HERMES was estimated to be Mach 4.5, it was obvious that radical changes to either warhead or missile would have to be made if this missile were used. It was apparent that either approach would require much design investigation, and it was decided to consider only the XW-8/REGULUS.[56]

It was found that the warhead compartment of the REGULUS was long enough to hold the basic Mk 8 Bomb assembly, but that little excess clearance was available, and that access to the nose of the weapon was difficult. Additionally, the center of gravity of the missile would be about 30 inches forward of its optimum location, and it was decided to delete the afterbody of the Mk 8. Tests were started to determine the terraballistics of the Mk 8 without its afterbody, and to ascertain whether the warhead would break away from the missile on impact with various surfaces.[57]

Another problem was the development of a mechanism to ignite the propellant of the internal gun device of the XW-8/REGULUS. In the drop bomb, this was accomplished by arming tapes, but the warhead application required either a device to pull the tapes at the proper point in the missile trajectory or a modification of the fuze.

yield would be the same as that of the Mk 8 Bomb. The warhead would function properly when subjected to missile impact speeds up to Mach 1.1 on water, earth, reinforced concrete and, if possible, harder targets. It would not broach or ricochet after impacts at angles between 60 and 90 degrees. The weapon would penetrate the target and detonate after coming to rest, and would be sufficiently watertight to function after water impact, followed by bottom impact.[64]

The Military Liaison Committee notified the Division of Military Application, October 3, 1952, that no requirement existed for design of penetration warheads capable of impact velocities higher than those of the REGULUS missile.[65]

Meanwhile, the Military decided that efficient use of the XW-8/REGULUS weapon required a high delivery accuracy. This was not possible with the existing missile system, and production requirements were deferred, awaiting refinement of the missile guidance system. Sandia was requested to complete its design work on the warhead, and the Navy was asked to proceed with scheduled flight tests.[66]

Successful component evaluation flights were conducted, and a successful warhead system test was held September 24, 1953. The Military Liaison Committee then suggested that, since there were few differences between the XW-8 Warhead and the extensively tested Mk 8 Bomb, further systems tests be held in abeyance.[67]

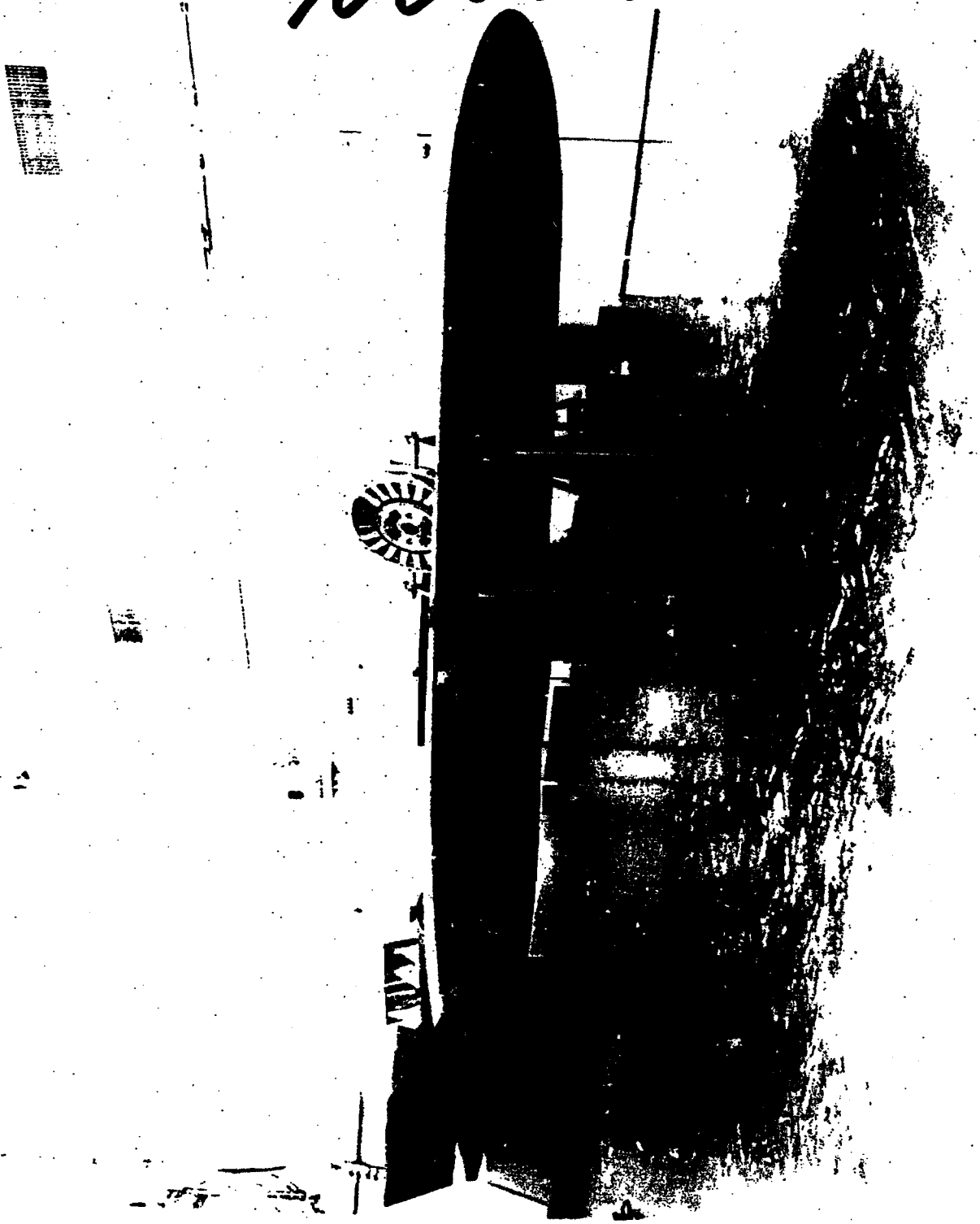
Design of the missile-warhead was completed in August 1954, and Report SC3483(TR), Status and Evaluation of the XW-8/REGULUS Warhead Installation at Design Release, was presented to the December 1, 1954 meeting of the Special Weapons Development Board.[68] The warhead was named the Mk 8 Mod 2, and production responsibility assigned to the Bureau of Ordnance.

The warhead contained three delay fuzes, two located on the side and one on the nose. (b)(3)

All requirements of the military characteristics were satisfied by the test program, although impact tests at less than 90 degrees were not conducted, and it was

not definitely determined whether the warhead would penetrate the target or break away on impact. However, Mk 8 Bomb tests had shown that satisfactory penetrations were achieved at entry angles as low as 30 degrees to the surface, and it was felt that the warhead would have similar satisfactory characteristics.

Subsequently, the possibility of developing a guidance system to effectively deliver the XW-8/REGULUS with pinpoint accuracy appeared remote. Consequently, on May 20, 1955, the Navy suspended activity in the program, together with work on the XW-11/REGULUS application.[69]



TX-10 External View

Subsequently, the Division of Military Application proposed that a lightweight, air-burst, gun-type missile warhead be developed,[74] and this suggestion received the backing of the Military Liaison Committee July 6, 1950.[75] It was proposed that Army Ordnance, then involved with the Mk 9 Shell, be requested to assist in design and development.[76]

Meanwhile, the lightweight, air-burst, gun-type bomb project had not been entirely forgotten, and the Military Liaison Committee, in a letter dated August 9, 1950, stated that the Joint Chiefs of Staff had established a requirement for the development of air-burst bombs sufficiently light in weight and small in cross section to be carried by high-speed tactical airplanes of the Air Force and Navy. It was felt that these bombs could be based on either implosion- or gun-type nuclear devices, and formal requests were made for both types.[77]

The subject was discussed in the August 16, 1950 meeting of the Sandia Weapons Development Board, with the Board agreeing to assume cognizance of the project. Two problems were immediately apparent: The development of a flexible fuzing system capable of attacking various tactical targets, and a weapon resistant to temperatures as low as -100°F.[78]

Sandia had meanwhile made a study of a lightweight bomb design and reported to AEC-Sandia August 17, 1950, that this could be produced by mid-1952. It was suggested that North American Aviation, Inc., be assigned the task of developing and manufacturing the outer case, internal support structures, and parts of the carrying pylon. Sandia would develop a fuzing and firing system, conduct drop tests, provide test and handling equipment, and act as project coordinator.[79]

On the same date, the Division of Military Application forwarded military characteristics for the above bomb. These required that the bomb be capable of tactical use by fighter, light bombardment, and attack (dive bomber) aircraft. The primary requirement was for external carriage, with alternate internal carriage being desired.

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The TX-G or Gun Committee agreed to accept interlaboratory responsibility for the TX-10.[26] The program was subjected to an intensive review in a Committee meeting of December 14, 1950, with the TX-10 being compared with the TX-7, an implosion design that had been pushed rapidly and which was now scheduled to enter stockpile earlier than the TX-10. It was felt by some conferees that the basic need for the TX-10 was eliminated by the advent of the TX-7. This latter weapon was larger than the proposed diameter of the TX-10 (27 inches versus 17 inches), but there appeared to be a sufficient variety of airplanes that could carry the TX-7.

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The problem was referred to the Sandia Weapons Development Board and discussed in a meeting December 20, 1950, with the Board being furnished copies of Sandia Report SC-1684(TR), A Critical Comparison Between the TX-7 and TX-10 Programs. This report noted that design was in work on a follow-on (and smaller) implosion device for the TX-7 (to be called the TX-12). The TX-12 would be less costly from the nuclear standpoint, would offer greater chances of increasing nuclear efficiency, and could be developed in about the same time scales. It was pointed out that work on the TX-10 would subtract effort from the TX-12, and that tactical use of the TX-10 (if manufactured in large numbers) would require major realignment of component production.

The Board noted that the TX-10 diameter would probably be smaller than the TX-7 or TX-12, but stated that further reductions in implosion-weapon diameter could be expected, as much nuclear design effort was currently being placed on implosion design improvements. After extensive discussion, the Board recommended that the TX-10 development be dropped in favor of the TX-12.[89]

The Division of Military Application wrote to Santa Fe Operations Office January 3, 1951, making reference to the above meeting. There were hopes that an interim TX-10 could be made available earlier than the TX-12, and it was suggested that the requirement for nuclear safing be eliminated and an external shape suitable for subsonic (but not necessarily supersonic) carriage be provided.[90]

The design status of the TX-10 was reviewed in the April 10, 1951 meeting of the Sandia Weapons Development Board. The bomb would be at least 17 inches in diameter and 2000 pounds in weight.

(b)(3), (b)(1)

The Board noted that the diameter and weight of the TX-10 exceeded the military characteristics, and that major reductions in these items could not be expected until the nuclear gun design was revised by Los Alamos.

(b)(3)

The project thus reverted to fundamental study of the problems of providing low burst heights, miniaturization, supersonic aerodynamics, and nuclear design improvements. Subsequently, the Military Liaison Committee canceled the TX-10 Bomb program May 7, 1952, noting that the Joint Chiefs of Staff had stated that a military requirement for the weapon no longer existed.

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Mk 11 Weapon

The Mk 11 Bomb, a gun-type penetrating weapon to be externally carried on high-speed aircraft, had its early beginnings when the gun-type device was considered for guided-missile application in March 1950. In this usage nuclear safing would be required to protect the missile launching site, and it would be necessary for the warhead to survive high impact velocities.[47]

Subsequently, the Division of Military Application expressed interest in a gun-type bomb that could be nuclearly safed and externally carried on high-speed aircraft.[99] The external shape of the Mk 8 did not lend itself to such carriage (due chiefly to its blunt nose), and it was felt that any modification of the nose shape would be complicated by the existence of the nose fuze. A nose redesign would require a lengthy effort, and it was suggested that a development program be authorized for a Mk II Elsie for such usage.[100]

The Military Liaison Committee released a set of desired military and technical characteristics for impact, delayed-action atomic bombs April 17, 1950. These characteristics described a bomb which could be nuclearly safed during aircraft carriage and that would be suitable for release at speeds up to Mach 1.2.[54] Subsequently, July 31, 1950, the Division of Military Application requested the Bureau of Ordnance to design a Mk 8-type weapon meeting these characteristics, and offered Sandia assistance in the task of fitting the design to appropriate carrying aircraft.[101] This proposal was accepted by the Bureau of Ordnance,[102] and nomenclature of TX-11 was assigned to the project November 29, 1950.[103]

There were three main gun-weapon problems being studied at this time: The ballistics problem relating to external carriage and release at high speeds; the nuclear safing problem, which concerned missiles as well as bombs; and the problem of increasing the resistance of the weapon to impacts on hard targets, such as reinforced concrete, rock and armor plate.

The Naval Ordnance Laboratory started to design the TX-11 fuzing system. It was felt that feasibility and preliminary design studies to establish tentative characteristics could be completed by January 1, 1952; and that detailed design

toss, glide and dive bombing. It would be capable of carriage and release at speeds up to Mach 1.4 and altitudes of 50,000 feet. It would be able to function satisfactorily after impacts on water, soil, reinforced concrete, and--to the extent practicable--harder targets.

The Board noted that the characteristics required external carriage at both subsonic and supersonic speeds, but a shape designed for one of these velocities would not be optimum for the other. It was felt that the design should be based on the assumption that the least drag during the major portion of the flight was desirable. Inasmuch as jet fighters en route to a target cruised at subsonic speeds, the bomb shape should be designed to meet this requirement.

The desire that the weapon be capable of penetration into hard rock was of concern. It was difficult to suitably define "hard rock," and there was felt to be a low incidence of this type of terrain near any probable targets. The scheduled design-release date was established as October 1953, with the bomb to enter stockpile in January 1955.[34]

The Bureau of Ordnance had been conducting tests of a soft-steel nose cap which, it was hoped, would crush and absorb the shock of weapon impact. These tests were not encouraging, and it was eventually decided to provide a Fiberglas nose cap. When the bomb was to be carried in an internal bomb bay, this nose cap could be removed.

Wind-tunnel tests had meanwhile narrowed the choice of weapon length to two possibilities; 146 and 169 inches. The Bureau of Ordnance recommended that the shorter figure be selected: It caused less drag at subsonic speed, it was compatible with all aircraft being considered for carriage of the bomb, and it could be carried internally in all aircraft except the B-50 without removing the nose cap.[109]

Full-scale drops at Inyokern produced excellent results.

(b)(1), (b)(3)

No detonation of the high explosive occurred during any of the impacts. Tests of 6-1/4-inch-diameter scale models against reinforced concrete 10 feet thick demonstrated that impact velocities between 2000 and 2200 feet per second could be

absorbed.[110] As a result of these tests, the length of the TX-11 was frozen at 146 inches on June 30, 1952, and the fin size was established at two bomb diameters, or 28 inches.[111]

Meanwhile, work had been undertaken on the design of a nuclear safing system,

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Glossary of Terms

Ad Hoc Working Group -- A group established by the Guided Missiles Committee to oversee the design of one particular missile-warhead installation.

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions related to atomic weapons.

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Contact Fuze -- A fuze that detonates the weapon by contact with the ground or target.

Crossroads -- Full-scale tests of Mk III Bombs, held at the Pacific Proving Grounds. The Bikini Baker shot was held July 25, 1946. Much effects data were gained, and the shot was so destructive that a scheduled deep underwater burst was canceled.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

Drag -- Resistance created by the passage of a shape through the air.

Field Command -- The local office of the Armed Forces Special Weapons Project, located on Sandia Base, Albuquerque, New Mexico.

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Joint Research and Development Board -- A Board established in mid-1946 as a postwar replacement for the Office of Scientific Research and Development. Its purpose was to suggest lines of research and development on military weapons and equipment.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Little Boy -- Code name for the gun-type weapon dropped on Hiroshima, Japan, August 6, 1945, during World War II. Originally called the Thin Man in reference to its long thin shape. The Thin Man was to use plutonium-239 as its nuclear material. Early samples of this isotope revealed that it contained small amounts of plutonium-240 which had a high preinitiation rate. A decision was then made to use uranium-235, allowing the length of the weapon to be radically reduced (due to the lower speed of assembly of the critical material). This change in outer shape was given the code name of Little Boy.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico. Called the Los Alamos Laboratory during World War II.

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Manhattan Engineer District -- A District of the Army Engineers established in August 1942 to provide the facilities that would be needed for design and construction of the atomic bomb.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

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June 1967

RS 3434/9
ATOMIC WEAPON
CATEGORY

HISTORY OF THE MK 12 WEAPON (U)

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Weapon Systems

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Information Research Division, 3434

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Sandia Systematic Declassification Review
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5/13/53	Division of Military Application cancels the TX-12 and requests concentration of effort on TX-12-X1 hard case design.
3/31/54	TX-12-X1 design discussed in meeting of Special Weapons Development Board and accepted.
5/1/54	Mk 12 Mod 0 design released.
12/54	Mk 12 Mod 0 Bomb enters stockpile.

Mk 12 Warhead

2/1/51	Military Liaison Committee notifies the Division of Military Application that the Air Force is contracting for Bureau of Ordnance development of an air-launched, free-flight rocket.
4/10/51	(b)(3)
6/5/51	Santa Fe Operations Office assigns nomenclature of XW-12.
7/13/51	TX-N Committee urges that XW-12 Warhead be assigned a high development priority.
10/29/52	Military Liaison Committee requests the Division of Military Application to undertake a preliminary investigation of an air-defense warhead.
11/14/52	Division of Military Application suggests that the study of an air-defense warhead include application to TALOS missile.
2/10/53	Military Liaison Committee notes that the Joint Chiefs of Staff have established a requirement for development of surface-to-air missiles with atomic warheads, with particular reference to the TALOS missile.
5/15/53	Field Command proposes set of military characterisitcs for a 22-inch-diameter air-defense warhead.

6/23/53	Bureau of Ordnance notes that XW-12/TALOS-W warhead installation cannot meet all the requirements for the air-defense warhead.
10/6/53	Armed Forces Special Weapons Project requests that XW-12 Warhead use as many Mk 12 Bomb components as possible, in order to expedite the development work.
1/18/54	Field Command requests Sandia to continue study of warheads capable of operation at high altitudes.
10/11/54	Field Command requests Sandia to delay Joint Task Group activities on the XW-12/TALOS-W, due to unavailability of missiles.
12/14/54	Proposal made that the XW-30 Warhead replace the XW-12.
11/21/55	XW-12/TALOS-W project terminated in favor of use of XW-30 Warhead.

History of the Mk 12 Weapon

Mk 12 Bomb

One of the military aims in the early development of atomic weapons was that of reducing the size and weight of the implosion bomb. Much progress had been made toward this end in the Mk 5 and Mk 7 programs, and, subsequently, the Los Alamos Scientific Laboratory continued intensive study in this area.

(b)(3)

This request was accordingly integrated into the 1951 Los Alamos program.[2]

(b)(3)

The desired military characteristics were forwarded by the Military Liaison Committee to the Division of Military Application March 6, 1951.[4] These called for an implosion weapon smaller than the TX-7 and established a maximum weight of 1200 pounds for the bomb. It was requested that the

Sandia presented a draft report of the proposed ordnance characteristics of the TX-12 to the October 12, 1951 meeting of the Sandia Weapons Development Board. The box dimensions of the tail fins had been established at 30 inches. A duplicate set of batteries would be incorporated to increase weapon reliability.

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The subject was discussed in the November 7 and December 11, 1951, meetings of the Sandia Weapons Development Board.[17,18] It was felt essential to

have complete flexibility of action, and a decision was made to provide a 7-option fuze, to include:

Radar air burst 1 with safe-separation time 1
Radar air burst 2 with safe-separation time 2
Radar air burst 1 with safe-separation time 2
Radar air burst 2 with safe-separation time 1
Timer air burst 1 with safe-separation time 3
Timer air burst 2 with safe-separation time 4
Contact burst with safe-separation time 5.[19]

Subsequently, Sandia made a survey of weapons then being designed, and proposed use of a tactical fuze on the Mk 7 and Mk 12 Bombs. This proposal would have standardized fuze design and simplified pilot operation, but a decision was made that flexibility was preferred.

The initial provisions for bomb carriage included a Navy wing rack with a separation of 14 inches between attachment lugs and an Air Force rack with 30 inches between lugs. In late 1951 the Navy changed the 14-inch rack to a 20-inch design. It was subsequently suggested that the mid portion of the bomb case be strengthened so that sway bracing would not damage the case. Initially, it was requested that work continue on the original case design, and that the strong case be provided in a modification, and this proposal was accepted by the Military Liaison Committee July 9, 1952.[20]

The barometric switches were deleted in early 1952.[21] A decision had been made to use the TX-12 only as a tactical bomb and in low-altitude releases.[22] The baroswitches were then unnecessary, as they were designed to prohibit arming of the X-unit at high altitudes and prevent inadvertent arcing. Additionally, low-pressure testing of X-units had demonstrated that there was little possibility of such arcing at altitudes up to 50,000 feet.

modification program, called the TX-12-X2, was instituted to provide a more rugged fin, a more powerful operating motor, and a gear train to carry heavier loads.[34] This modification was scheduled to appear in stockpile during December 1956, but difficulties with the fin actuation mechanism delayed production of acceptable Mod kits of the Mk 12 Mod 1 until February 1957. The stockpile was completely modified by November 1957, with the allowable fin operating speed being increased to 220 knots. Simultaneously, a set of canted lugs was provided, to provide better compatibility with AD-series aircraft.[35]

Mk 12 Warhead

The Military Liaison Committee notified the Division of Military Application February 1, 1951, that the Air Force was contracting for Navy Bureau of Ordnance development of an air-launched, free-flight rocket.

(b)(3)

This information was forwarded to Santa Fe operations Office with a request that some thought be given to this usage, but that work on the TX-12 Bomb not be delayed.[37]

Additional criteria covering this rocket-warhead combination were furnished by the Division of Military Application March 13, 1951. Possible uses of the weapon included support of troops and defense against mass aircraft raids. Since it was desirable to carry the weapon on small, fast aircraft, its size and weight were to be as small as possible, and it was hoped that the weapon shape would have minimum effect on aircraft performance. The range of the rocket would enable safe escape of aircraft and crew after weapon launch.

(b)(1), (b)(3)

It was noted that a time fuze might be best for certain targets, but that requirements for accuracy of burst height in low-altitude deliveries might well require a target-triggered system.[38]

(b)(3)

Subsequently, November 16, 1951, the Committee on Atomic Energy of the Research and Development Board (the postwar replacement of the Office of Scientific Research and Development) noted that the ability to transport and direct atomic warheads against military targets constituted a most serious problem. The Committee noted that, with development of smaller and lighter atomic warheads, delivery would no longer be restricted to large bombers, and that guided missiles and rockets would be available in the near future. The report urged that high priority be given to the development of an air-to-ground rocket with an air-burst atomic warhead, to be used by attack and fighter aircraft making target approaches at low altitudes.[41]

The Military Liaison Committee notified the Division of Military Application February 10, 1953, that the Joint Chiefs of Staff had established a formal requirement for development of surface-to-air missiles with atomic warheads. The immediate objective was the design of an air-defense system to deliver an XW-12 Warhead by means of the TALOS-W missile.[47] The TALOS was 30 inches in diameter and 30 feet long, and was in the shape of a cylinder with one set of four stubby fins at its midpoint and another set at its tail. The missile was fired vertically, then programmed over into horizontal flight at a speed of Mach 2 to its target, which could be 60 miles distant. The Atomic Energy Commission would provide the warhead, and the Bureau of Ordnance would have responsibility for the rest of the weapon, with the Johns Hopkins Applied Physics Laboratory acting as prime contractor for the Navy.

It was planned to carry engineering studies through detail design and fabrication of a limited number of nose sections, complete with simulated warheads or warhead components. These nose sections would be combined with tail sections and subjected to flight tests, starting December 1953, as the final step in establishing the feasibility of the missile as an atomic warhead carrier. A TALOS-W Coordination Committee was appointed and held its first meeting March 4, 1953,[48] and the program was placed in design development stage March 6, 1953.

The Coordination Committee met April 10, 1953. Sandia discussed safing and arming problems, and proposed that 5000 feet be established as an adequate safe-separation distance and that, for failures just off the launcher, there be no self-destruct provisions. Likewise, in the late boost phase and in the time interval between separation and the end-of-being captured phase, there should be no self-destruct provisions, as nuclear arming would not have been initiated by this time. For subsequent failures it was recommended that self-destruction be required. The Atomic

Energy Commission would supply the warhead, with all necessary testing and handling equipment, and the Navy would be responsible for the adaption kit, including the warhead primary power supply.[49]

Field Command proposed, May 15, 1953, a set of military characteristics for an air-defense warhead having an outer diameter of 22 inches.

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Due to a possible requirement for high quantities, it was requested that the warhead have minimum nuclear and monetary cost.

A maximum weight of 650 pounds and a length of 60 inches was desired. The warhead would have to withstand accelerations of ±50 g's along the longitudinal axis of the warhead and 10 g's along any axis perpendicular to this. Other environmental conditions included temperatures from -65°F to +165°F and altitudes from sea level to 80,000 feet. Nuclear insertion should be possible at any time during warhead flight except during high acceleration and boost. Operating cycles should not exceed 6 seconds for insertion, nor 3 seconds for retraction. The warhead, except for the nuclear capsule, should remain functionally ready for periods of at least 6 months when installed in the missile. The nuclear capsule should be capable of storage in the insertion mechanism for at least 30 days.[50]

The Bureau of Ordnance notified Field Command June 23, 1953 that the XW-12/TALOS-W warhead installation could meet some, but not all, of the above requirements for an air-defense warhead. It was pointed out that the proposal to the Joint Chiefs of Staff had been based on use of TX-12 Bomb components in the XW-12 Warhead. This did not provide an optimum weapon, but the decision appeared both practical and in the best interests of the Services. The Bureau noted that early flights of the TALOS-W program were scheduled for December 1953, that airframe hardware had been released for production, and that the first missile was being assembled. It was felt that the nuclear capsule could not resist a 30-day storage period in an uncontrolled atmosphere.[51]

At the meeting of the TALOS-W Coordination Committee on June 25, 1953, Sandia stated that delivery of production-type warheads to stockpile could be made by June 1955, provided that the approved military characteristics were similar to those proposed by Field Command and that an early resolution of the self-destruction problem could be achieved. Development of a new and smaller X-unit, which had been under way at Sandia since January, was given Committee support. Production of the TALOS-W by the Navy was promised for early 1955.[52]

The August 4, 1953 meeting of the Coordination Committee heard a Sandia report on the self-destruction mechanism. This report proposed rapid retraction of the nuclear capsule, achieved by applying a higher voltage than normal to the mechanism. This, combined with a modification to the retraction gear ratio, promised a faster retraction time than previously believed possible. The Committee approved the proposal and requested that Sandia provide a detailed design.[53]

The Armed Forces Special Weapons Project in Washington notified Field command, October 6, 1953, that the XW-12 Warhead should use as many components from the TX-12 Bomb as possible, in order to accelerate development of the warhead. It was recognized that the XW-12/TALOS was not an optimum warhead for air-defense use, as it made uneconomical use of fissionable material, could not operate at high altitudes without an artificial environment, and could not withstand long storage in the operationally ready condition (that is, with the nuclear components installed in the nuclear insertion mechanism), without an artificial environment. However, no changes which would delay development would be allowed unless these were required to ensure proper operation. It was hoped that the weapon would provide an interim capability with at least some of the desired characteristics. Complete design release of the warhead installation was scheduled for the second quarter of 1954, first production by the second quarter of 1955, and stockpile entry in the third quarter of 1955.[54]

Meanwhile, the Bureau of Ordnance had noted that the design of the missile/warhead had progressed to the point where it was necessary to provide a definite division of responsibilities in the development of the warhead adaption kit. The TALOS-W warhead was contained in an isolated inner body which held only the warhead and some adaption-kit components, all of which performed functions relating to warhead operations. It was thus felt that the Atomic Energy Commission should assume development responsibility for these components in order to assure proper warhead functioning, and the AEC was requested to take over cognizance of the safing and arming system, the self-destruction system, plus hardware and adapters.[55]

The Santa Fe Operations Office replied that prime responsibility for design and development of the TALOS-W adaption kit rested with the Bureau of Ordnance, and that there was no compelling reason to reassign any of the portions of the adaption kit. However, the AEC, in a subcontractorlike role, could undertake to design and develop any portions of the kit for the Bureau of Ordnance on a reimbursable basis.[56] This information was forwarded to the Navy Department by the Division of Military Application.[57]

Field Command wrote to AEC-Sandia January 18, 1954, noting that the use of an artificial environment, to ensure warhead operability at all TALOS-W flight altitudes, would be acceptable in order to expedite design release of the warhead installation. However, it was requested that Sandia continue work on a warhead capable of operation at altitudes up to 60,000 feet without an artificial environment in the TALOS-W, and up to 100,000 feet in other applications. Hopefully, components so developed could be used in any air-defense warhead.

Sandia replied, February 2, 1954, that the warhead was located in the duct of the missile's ram-jet engine, where the pressure was greater than in other locations. This, of course, did not exactly provide an artificial

malfunction on another. All warhead components had been design-released, and drawings and specifications had been completed and filed for possible future reference.[64]

On November 21, 1955, the Assistant Secretary of Defense officially terminated the XW-12/TALOS-W project.

Glossary of Mk 12 Terms

Abee -- A radar design that superseded the Archie, a development of the "Tail-Warning Charlie" radar that signaled the approach of an enemy aircraft.

Adaption Kit -- Those items peculiar to the warhead installation less the warhead; namely, the arming and fuzing systems, power supply, and all hardware, adapters, and the like, required by a particular installation.

AEC-Sandia -- The Sandia Field Office of the Atomic Energy Commission.

Albert -- A radar design that superseded the Abee.

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions related to atomic weapons.

Assistant Secretary of Defense -- Created by Department of Defense directive June 30, 1953, as part of DOD reorganization. Handles research and development activities of the DOD.

Barometric Switch -- A switch actuated by air pressure.

Bureau of Ordnance -- That part of the Navy Department having to do with design and procurement of ordnance.

Capsule -- The nuclear ~~assembly~~ element of an atomic weapon which, when subjected to compression in the implosion process, becomes supercritical and produces a nuclear reaction.

Centrifuge -- A device employing centrifugal force to stress weapons components. Consists of a horizontally mounted arm. On one end of the arm is placed the item to be tested; on the other end of the arm is placed a rocket engine. Firing of the rocket causes a high rotational speed of the arm.

Contact Fuze -- A fuze that detonates the weapon by contact with the ground or the target.

Detonators -- ~~Devices containing bridge wires which, when subjected to an electrical current, burn rapidly and act as a match to apply a flame to various points on the outer surface of the high-explosive sphere.~~ Explosive devices which when initiated by the X-unit signal the lens charges of the high explosive sphere.

Division of Military Application -- An AEC office that functions as liaison between the Military and the weapons designers and producers.

Field Command -- The local office of the Armed Forces Special Weapons Project, located on Sandia Base, New Mexico.

Fuze -- A combination of the arming and firing devices of a weapon.

Guided Missile -- A trajectile that is directed to its target while in flight or motion, either by a preset self-reacting device within the trajectile or by radio command outside the missile.

Implosion -- The effect created when a sphere of high explosive is detonated on its exterior surface. The force of the shock wave is directed largely toward the center of the sphere.

Inverter -- A device for converting direct current into alternating current.

Joint Chiefs of Staff -- An Army-Navy-Air Force group to determine policy and to develop joint strategic objectives of the Armed Forces.

Joint Task Group -- A military group established to test the stockpile-to-target sequence of a weapon.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the Atomic Energy Commission on all matters relating to military applications of atomic energy.

Missile Warhead -- The explosive or nuclear device carried by a missile.

Operation Tumbler-Snapper -- See Tumbler-Snapper.

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LOS ALAMOS SCIENTIFIC LABORATORY

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ON HETEROCATALYTIC DETONATIONS I. (U)

Hydrodynamic Lenses and Radiation Mirrors

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Report written by:

E. Teller
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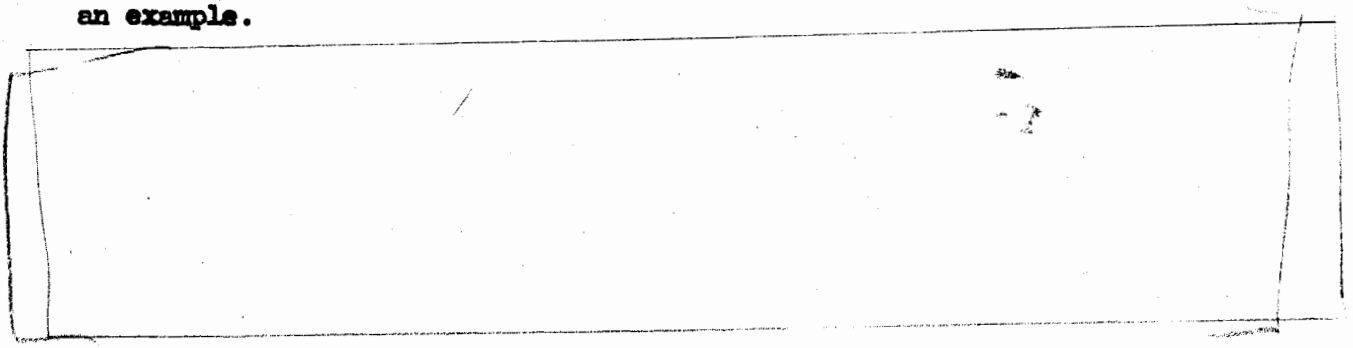
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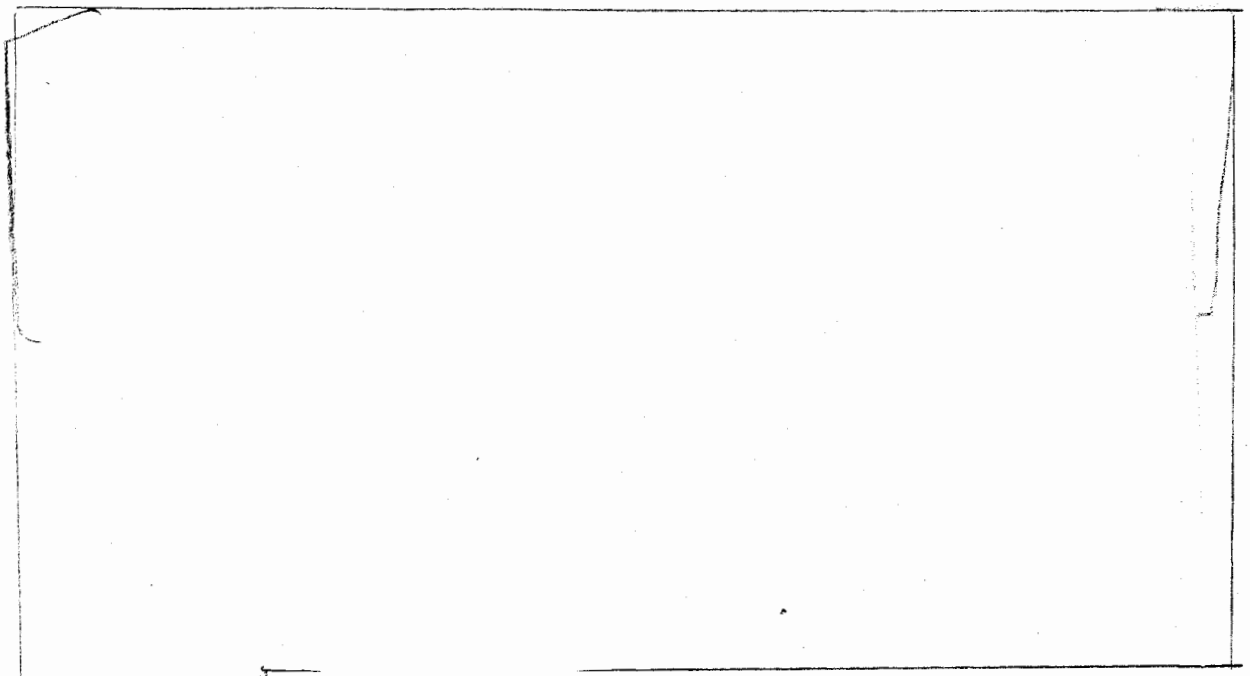
Hydrodynamic Lenses and Radiation Mirrors

Introduction

In this discussion the following general scheme is considered. By an explosion of one or several conventional auxiliary fission bombs, one hopes to establish conditions for the explosion of a "principal" bomb. This latter may be either a fission or a thermonuclear assembly.

We propose to discuss certain general features of such an arrangement. The main purpose of the "auxiliary" system is to induce very high compressions in the principal assembly. It is known (L. W. Nordheim, unpublished data) that, for example, in the "Alarm Clock" high compressions of the active core will permit economy in the tritium put initially into the system and may be instrumental in starting thermonuclear reactions in assemblies of a feasible size. Ordinarily one uses high explosives as the auxiliary system. Great compression can be obtained, but the size of the highly compressed region is small. In certain thermonuclear arrangements, like the Alarm Clock, the size and the mass of the material to be compressed is so great that inordinate amounts of HE would have to be used. We have the following situation in mind, as an example.

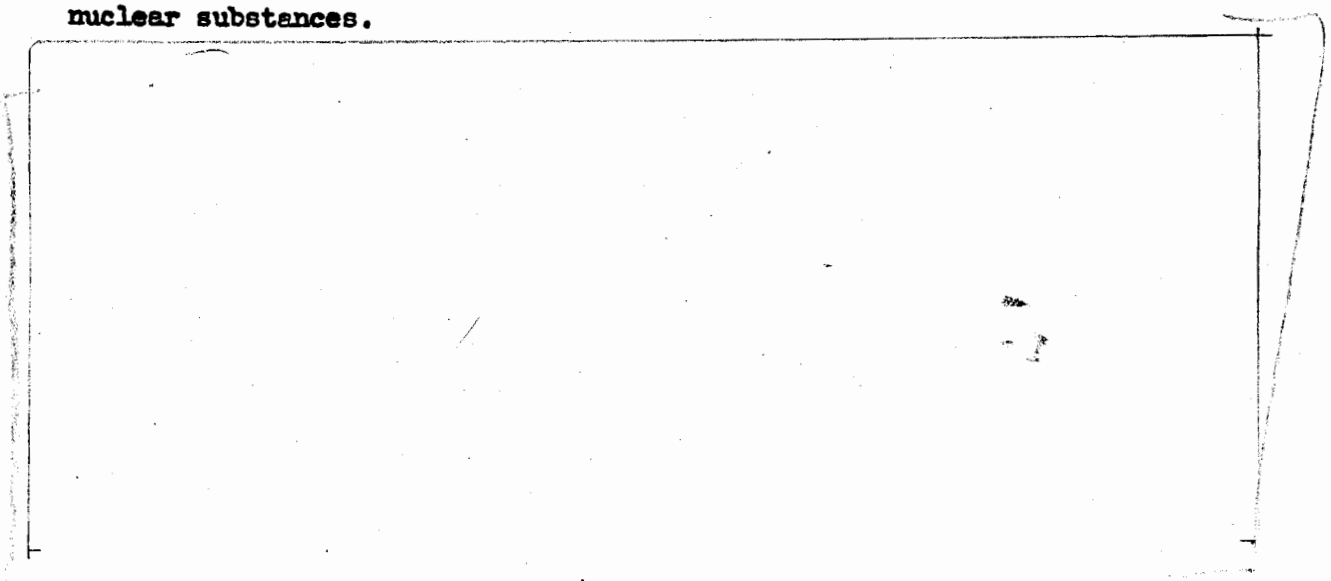




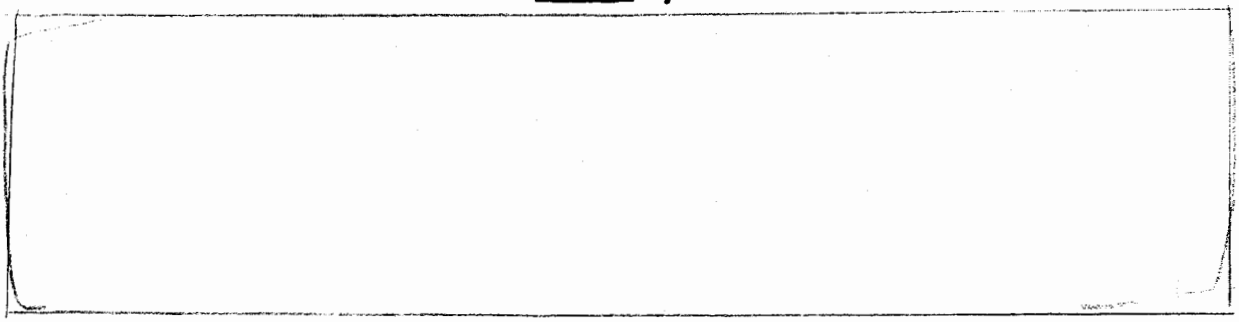
63

We shall discuss in the sequel the hoped-for compressions.

The arrangement might be called heterocatalytic, involving as it does a setting off of a reaction in one system by a reaction started in another material--the "auxiliary" arrangement is located at a considerable distance (from the purely nuclear point of view), like 50 cm to 5 meters. This is in distinction to hitherto-considered auto-catalytic schemes based essentially on self-implosions of a mixture of nuclear substances.



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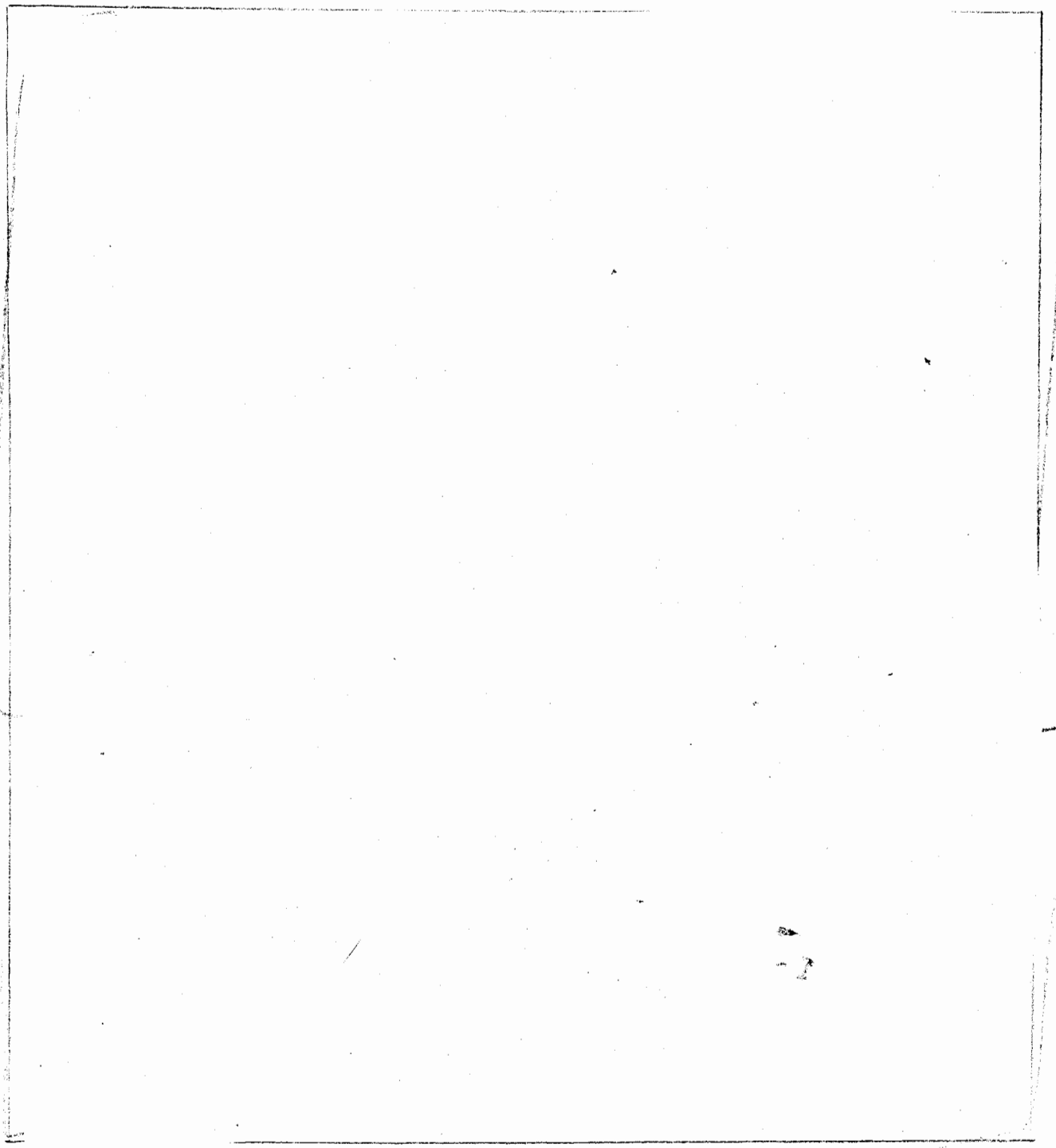


The difference of sound velocities is due to three reasons. One is the difference in average atomic weights, due primarily to the different degrees of ionization. Thus a light element like carbon would be almost completely ionized and would behave like a gas of approximate atomic weight 2. Uranium, on the other hand, would suffer approximately 10-fold ionization and would have an effective atomic weight near 8. The ratio four in atomic weights would give rise to a factor two in sound velocities. The higher velocity is of course to be expected in carbon.

A second reason for a difference in sound velocities is the fact that a completely ionized material acts like a monatomic gas with $\gamma = \frac{5}{3}$, whereas uranium, in which ionization is still proceeding, has probably a γ-value near 1.4. This will increase the ratio of sound velocities by another 10%.

The third reason is that the same shock strength will produce a lower temperature in a material of higher density since in each material the given energy density is distributed among more particles. This effect might give rise to temperature ratios as high as a factor four and to sound velocity ratios as high as a factor two. (In principle this effect could be made even greater but one would soon begin to lose by poor matching of acoustic impedance.)

It is, therefore, reasonable to assume that materials can be found in which sound velocities differ by a factor somewhere between 2 and 4. There should be no difficulty in making materials of any intermediate sound velocity.



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In fact, the essential parts of the design do not depend sensitively on complicated shapes and the necessary planning is, therefore, comparatively simple.

The proposals are outlined here extremely sketchily. Quantitative work to elaborate these general suggestions would have to include the following calculations:

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Report of the Manager
Santa Fe Operations
U. S. Atomic Energy Commission

July 1950 to January 1954

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CHAPTER I

Summary of SFO Progress, 1947 to 1954

Santa Fe Operations fulfilled its mission assignments for the period July 1947 to January 1954. Atomic weapons of required efficiency, variety and utility were developed, produced and placed in stockpile in conformance with constantly expanding military requirements and approved schedules. New weapons of greater destructive power, of greater efficiency, and of at least equal variety and utility were in development prior to production or were clearly foreseen as a result of research. A major store of other knowledge of great value to other national programs, such as military utilization and civil defense, was obtained through SFO or SFO-related activity.

Weapons-wise, the six and one-half year period encompassed the A-bomb or fission stage and concluded well beyond the threshold of the H-bomb or thermonuclear stage. History may refer to the period by its weapons, A-bomb and H-bomb. In the memory of SFO management it may well be characterized as the building period. It extended from the beginning to the essential completion of the job of building the organization, the physical plant, and the basic programs required for mission accomplishment.

Weapons-wise and otherwise the final six months, July 1 through December 31, 1953, were a period of transition. As of July 1, management was already shifting from the phase of major stress on organizing and building to one of major stress on consolidating and tidying-up administration and operations. Midway in the period the direction of the implosion weapon program was reversed from added expansion to major retrenchment when the Military slashed its requirements for training and for stockpile. As the period closed, plans for one new high explosives plant and projected increases in facilities at two others had been cancelled and studies were under way to determine the degree of need for the remaining high explosives production facilities. Accompanying the cutback on implosion weapons was a military determination for concentration on thermonuclear weapons. As the period closed, plans were under way for achieving the scheduled production, but largely through organizations and facilities already established during thermonuclear development. As in weapons, the final six months also brought major developments in other phases of Santa Fe Operations. Planning was well under way at the close of the period to adjust to the changes involved in bringing San Francisco Operations Office and the Livermore Laboratory into SFO, and to those involved in concentrating on development and production of thermonuclear weapons. ALOO

Because of the tremendous gains made in the past six and one-half years, and the remarkable crystallization of a large development and production complex achieved since mid-1950, SFO had never before been so ready to meet expanded and urgent national requirements. Starting almost from scratch, without adequate tools to perform its mission, it had forged its tools and at the same time achieved its atomic weapons mission. Today its organizational structure and large plant complex is at once basically sound enough to stand the load of increased and new requirements, and flexible enough to adapt to changed circumstances.

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1. JULY 1947 TO JULY 1950

The newly-created Atomic Energy Commission took over responsibility for the atomic energy program on January 1, 1947. On July 2 the Office of Santa Fe Directed Operations (now Santa Fe Operations Office) was established to administer the atomic weapons field program. Two weeks later, the present Manager of SFOO arrived at Los Alamos to be the first civilian manager of the project.

In mid-1947, Los Alamos Scientific Laboratory, assisted by a small Sandia Branch, was carrying the major weight of weapons manufacture. There was some production of mechanical components at the Army's Rock Island (Ill.) Arsenal. The Salt Wells Pilot Plant of Naval Ordnance Test Station, Inyokern, California, was producing high explosives. There was little participation by private industry. Two weapons types were being produced in extremely limited quantity. Units going into stockpile were laboratory-fabricated. The limited production chain had only one source for each major component. Three major modifications of one Mark weapon were in early development.

The SFOO assignment at the beginning of its operations represented a tremendous undertaking. It was required to build the mandatory physical plant and organization, while at the same time assuring continuous production of weapons, and maintaining basic and applied research for development of more powerful, more varied, or more efficient weapons. The scope and priority of initial assignment were direct reflections of the situation:

> To build and develop at Los Alamos, the heart of the program, a community that would be adequate to obtain and to retain the type of personnel required. This meant rebuilding and expanding the community.
>
> To provide a climate in which LASL could proceed with its job of basic nuclear research and development, and to provide a Technical Area physical plant adequate for the job.
>
> To organize and supervise an ordnance development, production, and testing complex, relieving LASL of these responsibilities.
>
> To expand production and facilities at other sites, in order to achieve a continuous flow of component parts.
>
> To evolve an organization competent to achieve basic management and program objectives.

ALOO

Approximately two and one-half peacetime years provided a relatively secure period unhampered by wartime expediencies, during which programs could be adequately planned and activated. The value of time for orderly development of a basic SFO structure was underwritten by national and international events near the end of the period. In the Autumn of 1949 Russia tested an atomic weapon, and SFO moved immediately out of its "peace-time" period into one of increased mission urgency and of "crash" programs. This was intensified in early 1950 with the decision to go all out on thermonuclear weapon development. It was further intensified three days before the end of the reporting period by the outbreak of the Korean War.

DOE/AL

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Subcommittee, consisting largely of SFO contractor personnel, made two major recommendations in the interest of reduced security costs without weakening national security: (1) Recognition that no security is involved in approximate yield of nuclear detonations in Nevada; and, (2) application of the reactor field's "black box" idea to those items of nuclear weapons which are clearly of a military and not AEC nature. A field classification board was established at Sandia in addition to the one at LASL.

Declassification

Declassification is necessarily highly centralized and is performed for SFO by an Assistant Director, LASL, advised by Senior and Responsible Reviewers (the latter at LASL and Sandia) and by field classification boards. The normal tendency to overclassify has been materially reduced and a continuing program to review classified material for downgrading or declassification has been continued. Formal declassification was accomplished during the three years on 585 items from LASL and 16 from Sandia. Publication of "The Effects of Atomic Weapons" and release of information in the Rosenberg-Greenglass cases opened a fairly large field of information which could be considered for declassification.

Security

Considerable program stabilization was achieved while planning and activating "crash" basis expansion. To provide coordinated service over a wide geographic area, security offices were established in New York and in Los Angeles. As of July 1953, SFOO had security responsibility in 423 security facilities, 25 per cent of the entire AEC's facilities. A key achievement was segregation of staff and operating functions, with the Office of Security providing over-all direction and with SFOO Field Offices tending more toward local administration and less toward operations. For instance, installation guarding was being performed by contractor employees (or the Military) at all points except Los Alamos. Particular SFOO emphasis was placed on continuous review, evaluation, and coordination of security programs and measures throughout SFO. Careful analysis and action made possible a reduction of more than 50 per cent in ratio of guards to total Q-cleared work force at major SFO installations, the 1950 figure having been one to seven and the mid-1953 figure one to seventeen. Reductions in size of limited access areas and institution of various personnel security safeguards permitted a 3,750 reduction in number of Q-clearances processed in fiscal 1953 as compared with 1952. Two permanent panels of Personnel Security Board members were set up in 1950 to assist in administrative review of personnel clearance cases. Document control measures were intensified. Classified documents on hand June 30, 1953, totaled 53,000,000 with unaccounted-for documents totaling 840.

Information

There was a heavy, continuing output of classified reports, primarily by LASL and Sandia, with efforts being made to prepare them in a form not containing critical weapon data and so permitting wider classified distribution. LASL formed a Weapons Test Report section to replace special groups previously organized for each test series and to provide centralized and uniform handling, with 275 such reports issued prior to mid-1953. In addition to the requirement for technical reports, Sandia also had a heavy requirement for preparation of training manuals for the Military.

AL00

LASL and Sandia issued 493 formal, nonclassified reports on scientific and technological subjects during the period. There was a continuing flow of unclassified research material, particularly from UCLA's medical school.

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CHAPTER II

The Weapons Manufacturing Organization

In accomplishing its primary missions of adding to the store of knowledge on the use of atomic energy for weapons and of delivering finished atomic weapons to stockpile, SFO operates in five broad areas: Government administration, research and development, testing, production, and storage. Two broad categories of components make up the final products: The explosive system (fissile and conventional) and the inert system (fuzing and case). Prior to July 1953, two general types of weapons were manufactured for stockpile: Implosion and gun, with the thermonuclear type still in the pre-stockpile-production stage. The technical and operating functions are performed almost wholly by contractors. The extensive organization of key, operating contractors is in turn supported by thousands of contracts with governmental, not-for-profit, and private enterprise agencies which furnish scientific, technical, production, and supply services. Government support and supervision are provided by a direct AEC organization in headquarters and field offices.

The initial three years of AEC stewardship were described as a period of building a staff, organization, and physical structure to match the developing programs. In July 1947, Los Alamos was the weapons organization. During the next three years the structure at Los Alamos was revised and strengthened, while simultaneously specialized capabilities were established elsewhere. In July 1950, it was projected that the basic structure was essentially complete, that only minor future expansion would be required. Reflecting new scientific discoveries and the changes in program requirements which developed after that date, the three years from 1950 to 1953 were in fact marked by major changes and expansions in the Santa Fe Operations organization—headquarters, field, and contractor—and in the physical plant.

This section presents an oversimplified picture of the development of philosophy, total organization, and plan of operations during six years from mid-1947 to mid-1953. It presents the key details of office and contractor location, physical plant, missions, and personnel. In order to show the full scope, a summary of the related Armed Forces organization is also presented.

4. FACTORS ENTERING INTO FIELD MANAGEMENT AND ORGANIZATION

ALOO

The mission assignment of SFO has remained unchanged, including research, development, testing, production, and custody of nuclear weapons. The scope has been materially expanded, for instance requiring organizational variations to cover implosion-type, gun-type, and thermonuclear weapons. A development in June 1952, was activation of Livermore Branch, University of California Radiation Laboratory, as a weapons development installation reporting to a new Operations Office at San Francisco. The new laboratory uses SFO facilities, particularly those at LASL, Sandia, Inyokern, and the two proving grounds, and

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requires detailed coordination with Los Alamos and with Santa Fe Operations Office, but it reports to AEC staff divisions in Washington.

Full field responsibility for performance of mission assignments continues to rest with the Manager, SFO. The parallel full field authority delegated in 1947, in keeping with the original philosophy of full decentralization, has been progressively limited, in keeping with an apparent swing toward a philosophy of centralization which seemingly accelerated after late 1950. These limitations have not been expressed in a redefinition of Operations Office authority, but in a series of actions each of which removed the control of some aspect of day-to-day performance and placed it with a Washington headquarters staff office.

There have been two major changes since 1947 affecting the line of command through which the Commission directs the field program. In 1947, the Manager, SFO, reported to the General Manager, the chief executive officer, with the Division of Military Application in the position of a staff division; in September, 1948, the General Manager delegated direct supervision of SFO to the Director, DMA. Paralleling the swing to centralization which became apparent in 1950 there has been an intensification of direct control exercised by specialized Washington staff offices over counterpart phases of field operation, expressed not through the command channel but directly through functional channels.

The expressed philosophy of AEC operation has remained constant, being that the maximum degree of operations and supply will be performed through contract with private enterprise. The application of the philosophy in SFO has been reviewed on several occasions, specifically with regard to the Zia and the University of California contracts at Los Alamos and on occasion with regard to operation of production facilities by the Military. In keeping with this philosophy, SFOO's plan of management has been to retain final field responsibility and control, providing policy and regulatory framework, and requiring performance. Manufacturing responsibilities are assigned by SFOO to its contractors in order to utilize to the fullest extent possible the management know-how, operating skills, and efficiency of private enterprise. To the fullest extent possible, authority is also delegated by SFOO to its field offices and to its contractors. Staff functions are retained by the Operations Office headquarters and field office organization. Technical and manufacturing functions are delegated.

5. SANTA FE OPERATIONS OFFICE

Prior to 1947, the Manhattan Engineer District managed and operated the nuclear weapons field organization which was largely centered in Los Alamos. From January 1, 1947, when the newly-created Atomic Energy Commission took over responsibility for the atomic energy program, until July 1947 the Military continued to provide supervision at Los Alamos. On July 2, the AEC established the Office of Santa Fe Directed Operations (now known as Santa Fe Operations Office) to conduct the weapons program. Two weeks later Carroll L. Tyler arrived at Los Alamos, becoming the first direct AEC Manager.

One of his immediate jobs was to organize a staff. There have been numerous reorganizations since, but the general outline of the staff formed by late 1948 has remained constant, changes largely reflecting new areas of key interest. Near the end of the first three years, the Santa Fe Operations Office headquarters and field staff was revised as a start toward providing, on the one hand, an operations-wide administration and, on the other, a more clearly-defined administration of the Los Alamos community.

DOE/ALO

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SFOO Transfer to Albuquerque

At the start of the present reporting period, July 1950, SFO headquarters was still at Los Alamos. It was then decided that reorganization and physical separation of SFO headquarters office from Los Alamos to another geographic location was desirable for several reasons: (a) Shortage of housing at Los Alamos; (b) rapid and widespread addition of SFO facilities outside of Los Alamos; (c) increased demand on the SFOO staff for supervision and coordination of programs extending beyond the Los Alamos area; and, (d) expansion in the testing, production, and stockpiling programs.

After considerable study Albuquerque was chosen as the location, and the former Simms Girl's School (then occupied by Sandia Laboratory personnel) was selected as the site. Albuquerque was selected after a survey of several cities because residential facilities were obtainable, major AEC and military installations were located there and contact with Los Alamos would not be difficult, and there was fair transportation to other SFO geographic areas.

SFOO was formally established at the Albuquerque location on June 18, 1951, and movement of approximately 300 employees was effected between August and October. Eleven staff offices and divisions at Los Alamos were transferred to Albuquerque. Also on June 18, 1951, the Los Alamos Field Office was created to take care of AEC interests at Los Alamos, and to it was transferred the Office of Community Management. LAFO became administrator for all phases, except program assumptions or changes thereto, of the Los Alamos Scientific Laboratory contract.

The reorganization and physical separation of SFO headquarters office from Los Alamos has resulted in improved SFO-wide planning, greater coordination and integration, more concentrated attention on local Los Alamos problems, and more effective staff utilization.

Development of Staff

The development of the present SFOO headquarters and field staff is indicated in the accompanying "Comparative SFOO Organization Chart 1950-1953." It is not fully descriptive. As of July 1953, SFOO had personnel assigned to numerous stockpile locations; had branch security offices in New York and in Los Angeles; had representatives stationed at Inyokern, Salton Sea, and Picatinny Arsenal; and had resident auditors stationed in Kansas City, Los Alamos, Los Angeles, and Rocky Flats.

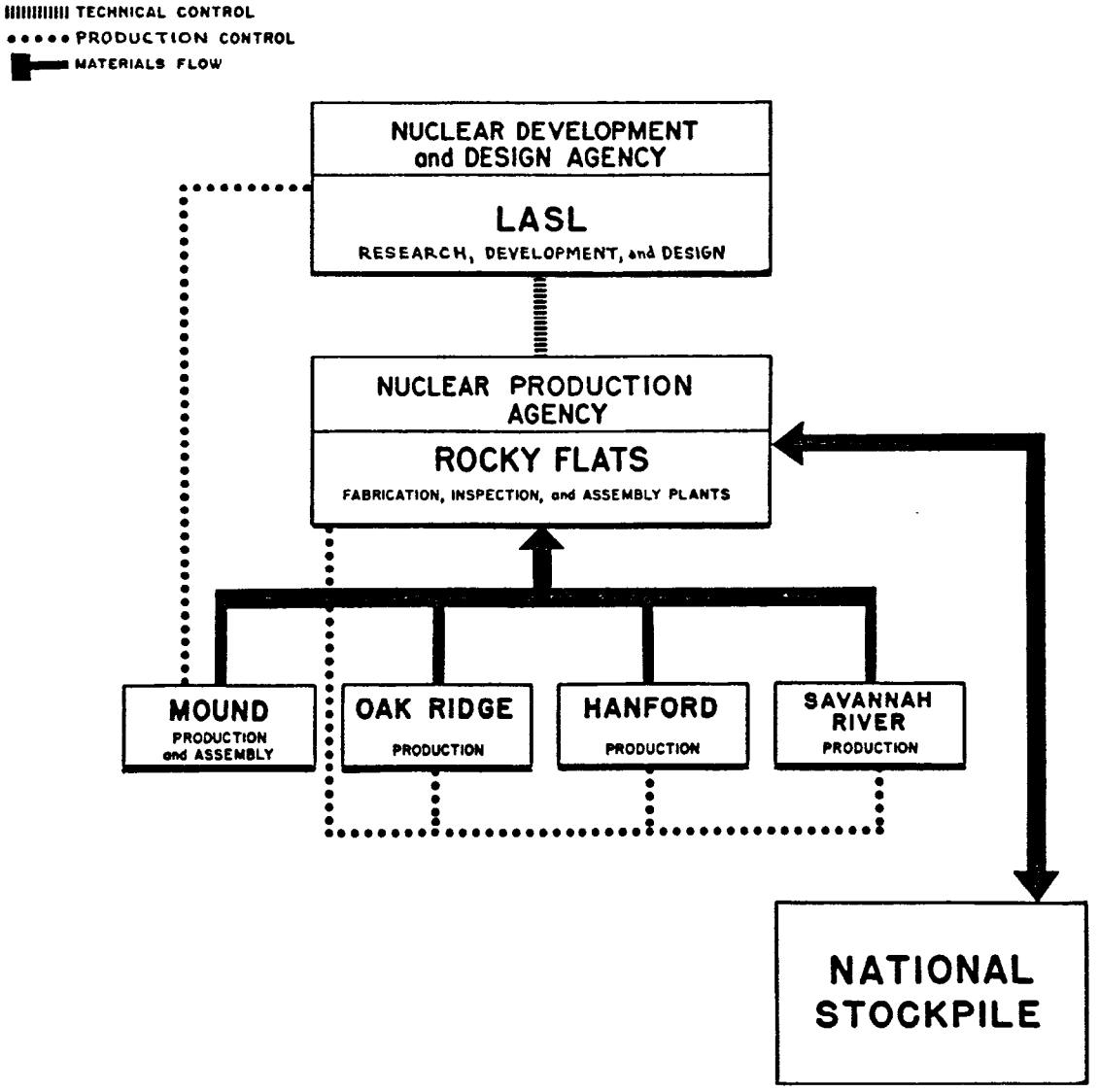
The staff Office of Test Operations was established on December 26, 1951, reflecting the need which had developed during 1951 and which would continue. The Office of Patent Attorney was established on June 15, 1952, with transfer of the SFO-wide responsibility from the LASL Patent Attorney. Not shown on the accompanying chart are several technical staff functions, which have from the start been accomplished by technical contractor personnel as direct staff assistants to the Operations Manager. The Director, LASL, is in effect technical staff officer and additionally head of the SFO programs of classification and of declassification, functions which he delegates to his Assistant Director for Classification and Security.

ALOO

There have been continuing changes throughout the past three years in key staff personnel. In anticipation of the move to Albuquerque, George P. Kraker, then Sandia Field Manager, was transferred to a new position as Deputy Operations Manager. Present personnel are noted in accompanying illustrations.

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NUCLEAR DEVELOPMENT and PRODUCTION OPERATIONS



AEC-SFOO
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The Manager, SFO, presented a resulting "Management Plan for Implosion-type Weapons" to the Commission on September 22, 1952, explaining that the plan would set a pattern for bringing additional production agencies into the program as developments might require. The plan as presented featured two points:

> Divesting Sandia Laboratory progressively of production functions, so that it could concentrate on technical functions, applying to Sandia the same principle which had proved resultful for LASL.
>
> Concentrating production function responsibility in a single contractor agency, this principle having been approved as applied to the nuclear production field, conforming with the Panel's guidance, and having been recommended by Sandia and by Bendix.

The plan established that implementing action would begin immediately, with transfer of functions to be progressive, with an overlap of up to two years before a clear cut and complete division would be achieved.

The full details of the plan presented in September 1952, have not been accomplished. There has been some divestment of non-developmental functions from Sandia Laboratory, and plans project accomplishment of this phase. Some production responsibilities have been transferred to the Kansas City plant. An Inter-plant Advisory Committee, of concerned plant, LASL, and SFOO personnel, has been established as a monitoring activity for high explosives fabrication and assembly.

The Mid-1953 Pattern of Operation Developed for Implosion Weapons

The operating philosophy thus proposed had been established for nuclear manufacture and for inert component development. It was uncertain whether it would be adopted for non-nuclear production. The pattern in effect in mid-1953 was as follows:

> Los Alamos, as the research, development, and design agency for the basic explosion system of all weapons;
>
> Sandia, as the research, development, and design agency for the inert system for all weapons to the extent that responsibility rests with SFO, and for related functions;
>
> Rocky Flats, as the production agency for nuclear components;
>
> Kansas City, becoming more and more a production agency for mechanical and electronic components; and,
>
> Inyokern, Burlington, Pantex, and Spoon River sharing production of high explosives.
>
> Picatinny Arsenal, producing detonators.

ALOO

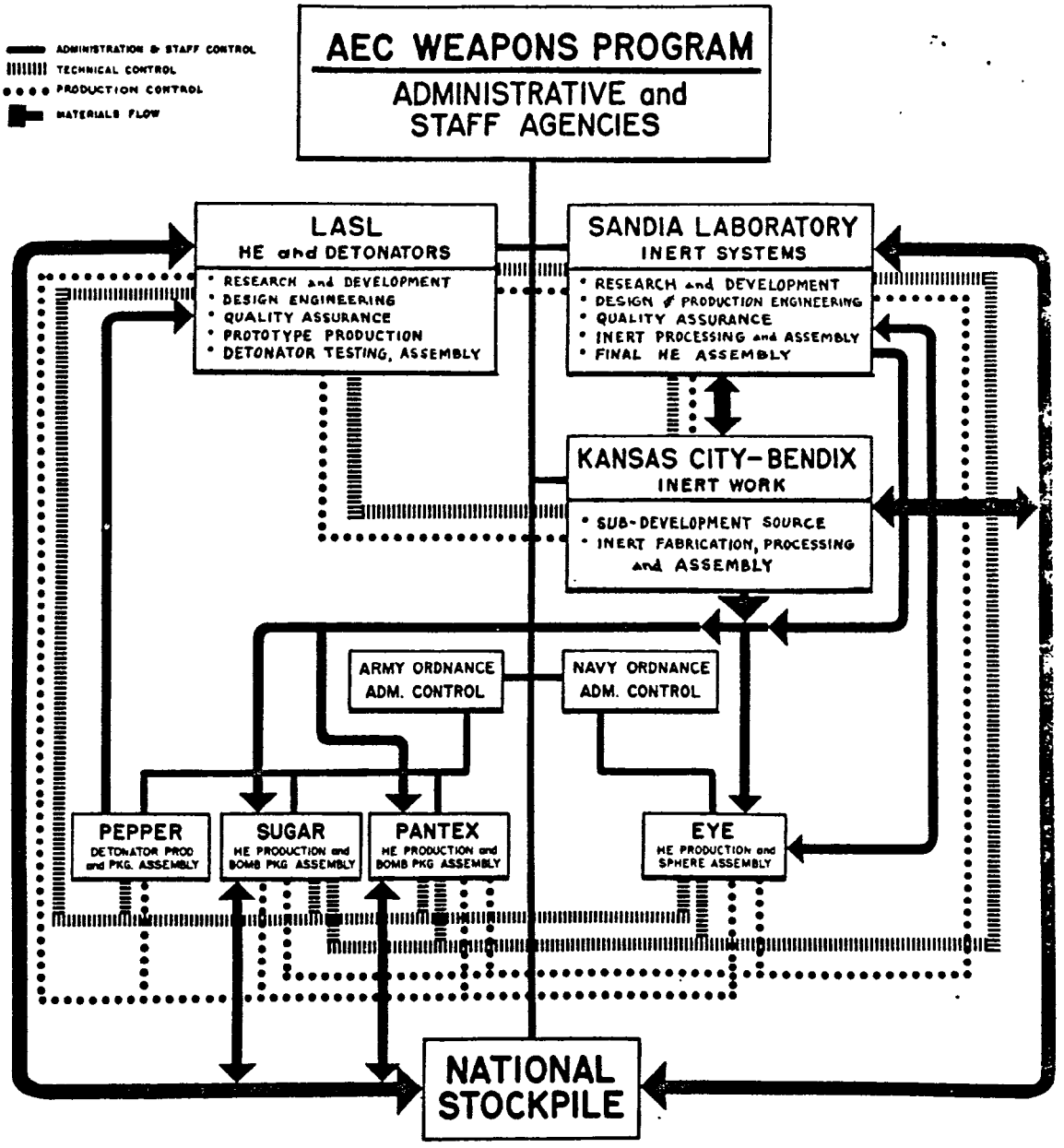
The Nuclear Component System

The accompanying chart presents a clear picture of the system.

LASL, operated by University of California, was the nuclear development agency with full responsibility under AEC program approval and program controls. It had the technical

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NON-NUCLEAR IMPLOSION WEAPONS OPERATIONS - JULY 1953



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functions of: Research and development, product design, test and evaluation, quality assurance, and preparation of standards for stockpile surveillance. It performed only developmental and engineering production, including fabrication and assembly of nuclear components.

Rocky Flats plant, operated by Dow Chemical Company, when fully operative would be the nuclear production agency with full responsibility subject to AEC controls and to LASL technical supervision, probably for all weapons types. It would have responsibility for: Production (process) engineering; fabrication of uranium and plutonium units in its own plant, and procurement from AEC fabrication plants; receipt, inspection, and assembly of nuclear capsules, and shipment to stockpile; other phases of final inspection and assembly; other phases of nuclear production procurement; and assisting Los Alamos in process engineering during development by coordinating startup of new production at the other installations.

Included in the production system were:

Mound Laboratory, for initiator fabrication (reports to OROO);
Industrial sources, for container fabrication;

Oak Ridge (OROO), Hanford (HOO), and Savannah (SROO) for nuclear fabrication.

Procurement flowed from AEC plants and from private industry to the production agency; and final product flowed from the production agency to stockpile.

The High Explosive System

LASL remained the development agency for HE and detonator components, retaining technical functions only. It performed only developmental or prototype production, including fabrication and assembly. (As of July 1, 1953, shipment of detonators was still from producer to LASL but agreement had been reached to ship from producer to stockpile.)

Inyokern (California) Salt Wells Pilot Plant, operated by Navy Ordnance, performed process engineering, tooling design, and pilot plant for new HE, other HE fabrication and assembly.

Burlington (Iowa) plant, contract with Army Ordnance for operation by Silas-Mason Company, and Pantex (Texas) plant, contract with Army Ordnance for operation by Procter & Gamble Defense Corporation, performed HE production and weapon assembly.

Spoon River (Illinois) plant was under construction, to be operated by Thompson Products Company, initially for HE production and assembly. A second Project Plum was projected, in view of existing requirements, for HE production and weapon assembly, perhaps through addition of production lines at Burlington and Pantex.

Picatinny Arsenal (New Jersey), operated by Army Ordnance, performed detonator production.

ALOO

It was projected that over a period of years as Thompson Products developed a capability, responsibility would be transferred there for Inyokern's process engineering, tooling design, and pilot plant operation. Spoon River would thus become the leadoff plant on production of new models and development and procurement for the entire high explosive system.

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The Inert Component System

Sandia Laboratory, operated by Sandia Corporation, remained the development agency for inert bomb and warhead installation components of all weapon types. It would eventually retain only technical functions, plus developmental or prototype fabrication and assembly.

Kansas City plant, operated by Bendix Aviation, was becoming the production agency for mechanical and electronic components. It might eventually have full responsibility, subject to AEC controls and to Sandia technical supervision. As of July 1, 1953, it had responsibility for: Some measure of process engineering; procurement from private industry; logistic support of HE plants; inert fabrication and assembly; and some base spares procurement.

The Pattern of Organization for Other Weapons Types

During the three years prior to July 1953, SFO developed and produced gun-type weapons and missile warhead installations, and conducted an extensive thermonuclear development program. The preceding paragraphs on development of the SFO organization for contractor operations dealt essentially with the organization for implosion-type weapons. There were variations and there were responsibilities assigned elsewhere as far as gun-type, missile warhead installation, and thermonuclear activities were concerned. These are described briefly below.

Gun-Type Weapons Manufacture

A penetration weapon program was operated jointly by SFO and the Navy. LASL was responsible for the nuclear phases. Sandia had responsibility for final design, environmental testing, development of handling equipment, and certain technical studies of fuzing and weapon effects. The Navy performed development and related production of the gun mechanism and ordnance.

Active work on development of an artillery-fired atomic projectile began after mid-1950. It was a joint LASL-Sandia program, with Picatinny Arsenal handling the bulk of the development work under SFO guidance.

As of July 1, 1953, responsibility for future gun-type work was divided: LASL and Rocky Flats, nuclear development and production; and Armed Forces (Army and Navy), non-nuclear design and production.

Missile Warhead Installations

Sandia Laboratory has been engaged actively in the development of atomic warhead installations for missiles, both guided and free ballistic, since October 1950. Inasmuch as the basic explosive system is in general identical with other implosion-type bombs, LASL has not needed to conduct developmental programs, Sandia now acting as the LASL agent in this respect. Future developments may bring LASL directly into the picture, as for anti-aircraft missiles.

AL00

Following considerable exploratory work, the Military Liaison Committee requested in November 1950 that atomic warheads be developed for a number of specified missiles. It became immediately apparent that in addition to problems associated with the basic warhead, integration of the missile guidance system and the warhead arming and fuzing system would constitute a major area of investigation and development; and that, aside from technical questions, division of development and production responsibilities between SFO and DOD

would require resolution. With concurrence of DOD and AEC, the Special Weapons Development Board was designated late in 1950 as the agency to determine division of arming and fuzing responsibilities. The Board did allocate and set up some Ad Hoc Working Groups. Subsequently, it was agreed that after the first four atomic warhead installations, the Military would assume the arming and fuzing responsibilities. As a consequence, the Ad Hoc Working Groups are now in the process of reconstitution into Joint Project Groups reporting to: the CG, FC, AFSWP; President, Sandia Corporation; and the designated DOD agency as principals.

Because of the large number of missiles designated to carry atomic warhead installations, it was evident that a high degree of standardization would be required. Considerable progress has been made in the direction of interchangeable warheads, not only between several missiles but also between a warhead and the associated free-fall bomb. This has resulted in the so-called "Maximum Bomb Availability Plan" whereby all warheads are to be stockpiled with their fuzes in bomb configurations until the bomb requirements are satisfied. Bomb-to-warhead conversion components and complements (analogous to fuzes) will also be stockpiled to provide the conversion capability to missile warhead installations when desired. Lately, considerable development effort has been devoted toward simplification of the bomb-to-warhead conversion process. Employment of standardized weapon components (i.e., baroswitches, radars, etc.), test equipment, and handling equipment has resulted in significant savings in both bomb and missile warhead installation programs.

Thermonuclear Weapons Development

Since an intensified research and development program was directed in January 1950, primary responsibility has rested with Los Alamos Scientific Laboratory. During development an organizational framework was developed which included American Car & Foundry Company, and extensive cryogenics assistance from National Bureau of Standards, Cambridge Corporation, and Herrick Johnston. It may be assumed that the developmental organization will point the way for the production organization. Future production will require the resources of the nuclear, high explosive, and inert production system. Added to this will probably be the ACF, Cambridge, and NBS facilities to meet unique requirements.

The Organizations Developed for Nuclear Field Tests

Los Alamos Scientific Laboratory originally carried almost all of the SFO responsibility for nuclear field tests. LASL still carries very heavy responsibilities but by mid-1953 the technical responsibility was being shared by Sandia Laboratory and to some extent by Livermore, and a considerable measure of administrative responsibility had been transferred to SFOO, and, in certain respects, to military participants.

Overseas Tests

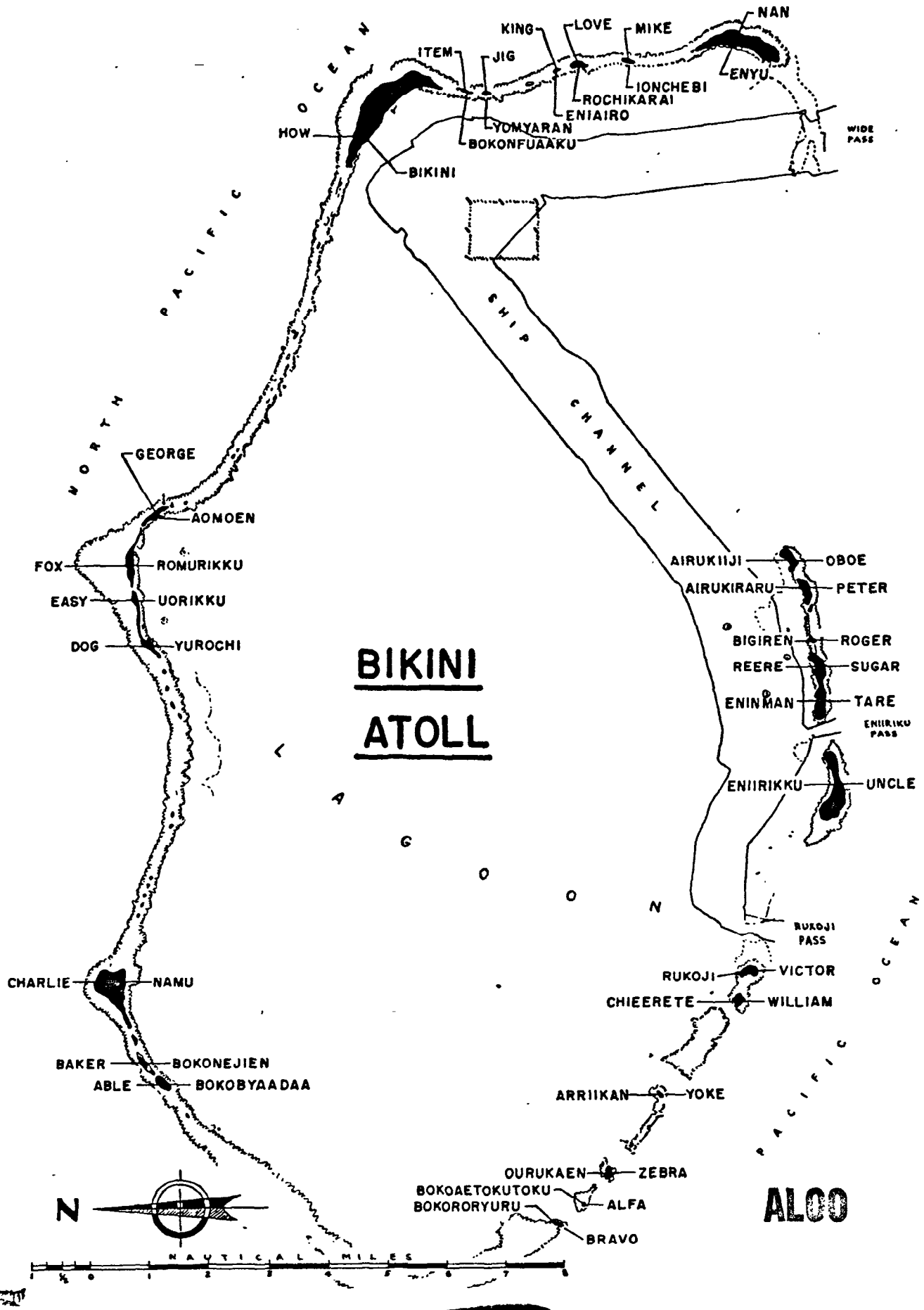
All overseas tests, beginning with Bikini in 1946, have been conducted by a joint task force commanded by a military officer and with responsibility for the scientific and technical phases and, beginning in 1948, many maintenance, construction and other support phases, resting with SFOO and its key contractors.

Executive agent responsibility has been rotated between the military departments with the Chief of Staff, U.S. Army, being agent for Sandstone; the Chief of Staff, U.S. Air Force, agent for Greenhouse; and the Chief of Staff, U.S. Army, agent for Ivy and Castle. During the period between operations, the JTF Commander's responsibility has been limited to planning and coordination of preparations for the operation, and to providing military support in the form of transportation, communication, etc.

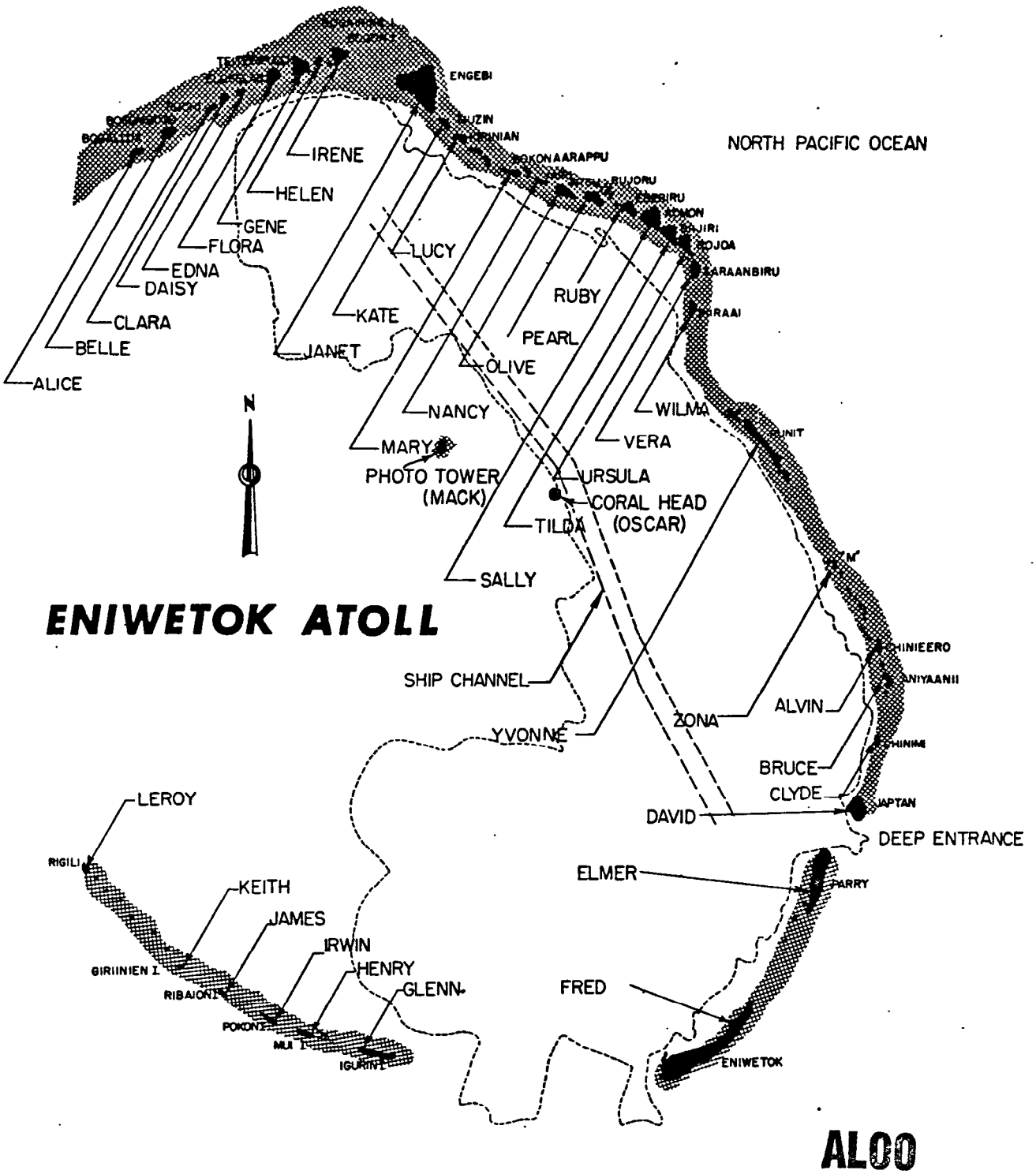
REALIGNMENT OF PLANNED FUNCTIONS, BY FACILITY
June 30, 1950, June 30, 1953, and Next Three Years

Facility	Functions as of June 30, 1950	Present Functions June 30, 1953	Planned Functions During Next Three Years
Los Alamos Scientific Laboratory	Weapons Research & Development Pilot Nuclear Fabrication Pilot Detonator Fabrication Detonator Fabrication Pilot HE Fabrication HE Fabrication -- -- -- -- -- -- -- -- Technical Manuals	Weapons Research & Development Pilot Nuclear Fabrication Pilot Detonator Fabrication -- -- -- -- -- -- -- -- Pilot HE Fabrication -- -- -- -- -- -- -- -- Pilot TN Fabrication Technical Manuals	Weapons Research & Development Pilot Nuclear Fabrication Pilot Detonator Fabrication -- Pilot TN Fabrication Technical Manuals
Sandia Corporation	Research & Development Non-nuclear Implosion Weapon Fabrication Implosion Weapon Assembly -- -- -- -- -- -- Procurement T&H Equipment Base Spares Procurement Technical Manuals	Research & Development Non-nuclear Implosion Weapon Fabrication Implosion Weapon Ass'y (reduced) Pilot TN Fabrication (Non-nuclear) Procurement T&H Equipment Base Spares Procurement Technical Manuals	Research & Development Non-nuclear Implosion Weapon Fabrication (less) Implosion Weapon Ass'y (reduced) Pilot TN Fabrication (Non-nuclear) Procurement T&H Equipment (reduced) Base Spares Procurement (reduced) Technical Manuals
Burlington Field Office (Iowa Ordnance Plant)	HE Production -- -- -- -- -- --	HE Fabrication Weapon Assembly	HE Fabrication Weapon Assembly
Pantex Field Office (Pantex Ordnance Plant)	-- -- -- -- -- -- -- -- -- -- -- --	HE Fabrication Weapon Assembly	HE Fabrication Weapon Assembly
Inyokern	HE Fabrication -- -- -- -- -- --	HE Fabrication Pilot Plant for new HE	HE Fabrication Pilot Plant for new HE
Rocky Flats Field Office	-- -- -- -- -- -- -- -- -- -- -- --	Nuclear Fabrication Nuclear Process Engineering	Nuclear Fabrication Nuclear Process Engineering
Kansas City (Project Royal) Field Office	Logistic Support of HE Plants Inert Fabrication/Procurement and Assembly -- -- -- -- -- -- -- -- -- -- -- --	Logistic Support of HE Plants Inert Fabrication/Procurement and Assembly Base Spares Procurement -- -- -- -- -- --	Logistic Support of HE Plants Inert Fabrication/Procurement and Assembly Base Spares Procurement (increased) Production Agency
Spoon River Field Office	-- -- -- -- -- -- -- -- -- -- -- --	-- -- -- -- -- -- -- -- -- -- -- --	HE Fabrication Weapon Assembly
Project Pepper	Detonator Fabrication	Detonator Fabrication	Detonator Fabrication

DOE/MD
ALOS


BIKINI
ATOLL
NORTH PACIFIC OCEAN
SHIP CHANNEL
LAGOON
PACIFIC OCEAN
NAN
KING
LOVE
MIKE
ITEM
JIG
ENYU
IONCHEBI
ROCHIKARAI
ENIAIRO
YOMYARAN
BOKONFUAAKU
HOW
BIKINI
WIDE PASS
GEORGE
AOMOEN
FOX
ROMURIKKU
EASY
UORIKKU
DOG
YUROCHI
AIRUKIIJI
OBOE
AIRUKIRARU
PETER
BIGIREN
ROGER
REERE
SUGAR
ENINMAN
TARE
ENIIRIKU PASS
ENIIRIKKU
UNCLE
RUKOJI PASS
RUKOJI
VICTOR
CHIEERETE
WILLIAM
CHARLIE
NAMU
BAKER
BOKONEJIEN
ABLE
BOKOBYAADAA
ARRIIKAN
YOKE
OURUKAEN
ZEBRA
BOKOAETOKUTOKU
ALFA
BOKORORYURU
BRAVO
N
NAUTICAL MILES
ALCO

61


NORTH PACIFIC OCEAN
ENGEBI
IRENE
HELEN
GENE
FLORA
EDNA
DAISY
CLARA
BELLE
ALICE
LUCY
KATE
JANET
OLIVE
NANCY
MARY
PHOTO TOWER
(MACK)
RUBY
PEARL
WILMA
VERA
URSULA
CORAL HEAD
(OSCAR)
TILDA
SALLY
N
ENIWETOK ATOLL
SHIP CHANNEL
YVONNE
ZONA
ALVIN
BRUCE
CLYDE
DAVID
DEEP ENTRANCE
ELMER
FRED
LEROY
KEITH
JAMES
IRWIN
HENRY
GLENN
ENIWETOK
ALOO

[redacted]

9. THE MILITARY ATOMIC WEAPONS ORGANIZATION

The Armed Forces Special Weapons Project (AFSWP) has its headquarters in Washington and its Field Command at Sandia Base. It coordinates all military assistance to AEC and provides special services to the Army, Navy, and Air Force in the military application of atomic weapons.

It was activated on January 29, 1947, to provide a jointly staffed Army-Navy atomic energy organization. After passage of the National Security Act on July 29, 1947, the Air Force was represented.

Since 1947, the assignments of AFSWP have multiplied steadily. Its earliest functions included military participation in research and development of atomic weapons in coordination with AEC, and coordination through established agencies of the radiological safety measures of the Armed Services. Both of these functions applied to the 1948 overseas tests. In 1949, AFSWP was assigned responsibility for determinations in the field of effects of atomic weapons and participated heavily in the overseas and continental tests of 1950-1953.

On August 1, 1952, Field Command-AFSWP established a Directorate of Weapons Effects Tests. Its Director is a Deputy Manager for continental tests.

AFSWP now functions in the over-all military application of atomic energy for the Army, Navy, and Air Force by providing the following services: specialized training; storage and surveillance in conjunction with AEC; planning of continental and overseas tests with other affected agencies; determination of weapons effects; consolidation of Armed Forces' requirements for procurement of atomic weapons other than War Reserve requirements; assistance, as required, in the development of atomic weapons; assembling of atomic weapons; other technical services to the Armed Forces as required.

Air Force support of the Commission's atomic weapons program is a major factor in many phases of the program. Much of the responsibility, particularly in the testing phase, rests upon the Air Force Special Weapons Center, headquarters Kirtland Field, Albuquerque.

The Air Force Special Weapons Center evolved from the Tactical and Technical Liaison Committee established at Kirtland AFB in 1947 through the activation of the Special Weapons Command in December 1949, and the subsequent transfer of the Command to the Air Research and Development Command. It is now one of eight centers under the jurisdiction of the latter Command.

The mission of Air Force SWC includes development testing and operational suitability testing of atomic and other special weapons; research as related to such tests; the development of associated equipment for nuclear weapons; and planning, control, and operation of special test facilities. It provides support to the Commission and its scientific contractors, including LASL and Sandia Laboratory.

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During the last three years, the Commission's relationships with the Military have become progressively more complex. The Department of Defense has entered the development field as a co-equal collaborator with AEC on numerous joint projects, with prime responsibility of its own in substantial areas of weapon development and design. As a result, it has become necessary to establish special direct working relationships with the individual services while being careful at the same time to insure that the values of AFSWP as an integrating agency are not lost.

DOE/ALO

[redacted]

[redacted]

AFSWP liaison officers continue on duty in many departments of Sandia Corporation, and maintain liaison with Los Alamos Scientific Laboratory. The Special Weapons Development Board, comprised of representatives of AFSWP, LASL, and Sandia Corporation, constitutes the official forum at which are developed formal recommendations on the development and standardization of atomic weapons. Guidance of joint AEC-DOD programs rests with Joint Project Groups whose membership comprises representatives of either LASL or Sandia, carrying the technical interests of AEC; the "cognizant service", Army, Navy, or Air Force, which carries the technical responsibilities for DOD; and AFSWP, which coordinates functions on behalf of all the Armed Services. Authority of the Joint Project Groups derives basically from general agreements between AEC and DOD.

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DOE/AD

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CHAPTER III

Achievements and Nature of Mission Programs

By broad category, Santa Fe Operations conducts programs of research, development, testing, production, and storage, the results of which are measured by the store of knowledge valuable to military application and by the utility and numbers of weapons in stockpile. The purpose of this chapter is to summarize the mission achievements of SFO and to sketch the nature and something of the extent of operations in the Los Alamos and Sandia areas including nuclear field tests, and including with relation to stockpile production an indication of the extent of weapons inspection and scheduling activities.

10. SUMMARY OF DEVELOPMENT, PRODUCTION, AND STORAGE ACHIEVEMENT

In 1945, only two types of bomb—and only two bombs—were available to the Military. One of the most important fields of development for national defense was to provide wide ranges both in yield and in size and weight in order to allow the Military to select bombs appropriate to the target and to the available delivery vehicles. Another important reason for reduction in size and weight of bombs was to enable the Military to use a wide variety of vehicles to carry atomic bombs and to gain greater range of action through reduction in load.

Progress Made Since 1945 Through Research and Development

DELETED

(c) produced a range of implosion bombs now in stockpile varying in diameter from 30 to 60 inches, in weight from 1,600 to 8,000 pounds, and in yield up to [redacted] not including a smaller sized model in development; and (d) produced a system of interchangeable cores and bombs so that yield and bomb size can be chosen relatively independently.

ALOO

The advantages of flexibility indicated above are difficult to measure numerically, but are certainly comparable with advantages in increased efficiency of utilization of fissionable materials. The effects of the latter could have been accomplished by very large expenditures leading to increased production of fissionable materials, those of the former could not have been attained except through research and development.

[redacted]

STATUS AND NUMBER OF WEAPON PROGRAMS, JULY 1950 and JULY 1953
(Status and Number—see notes)

Program	Stage 1		Stage 2		Stage 3A		Stage 3B		All Stages	
	July'50	July'53	July'50	July'53	July'50	July'53	July'50	July'53	July'50	July'53
1. NEW WEAPONS										
(a) Implosion-Type Bombs	2	1	0	1	3	1	1	4	6	7
(b) Gun-Type Bombs	0	0	2	1	1	0	0	1	3	2
(c) TN-Type Bombs	0	2	0	3	0	0	0	0	0	5
(d) Artillery Shells	0	2	1	1	0	0	0	1	1	4
(e) Warhead Installations	0	9	0	10	0	3	0	1	0	23
(f) TOTAL, a + b + c + d + e	2	14	3	16	4	4	1	7	10	41
2. MAJOR WEAPON-MODIFICATIONS										
(a) Implosion-Type Bombs	0	0	0	1	0	2	0	2	0	5
(b) Gun-Type Bombs	1	0	0	0	0	0	0	1	1	1
(c) Other	0	0	0	0	0	0	0	0	0	0
(d) TOTAL, a + b + c	1	0	0	1	0	2	0	3	1	6
3. GRAND TOTAL, 1(f) + 2(d)	3	14	3	17	4	6	1	10	11	47

NOTES:
1. Stage 1 indicates that studies incident to formulation of program are being made.
2. Stage 2 indicates that full-scale design and development is underway.
3. Stage 3A indicates that development is completed or nearly completed, and that action essential to getting into production has been initiated or completed, but first unit has not come off the production line.
4. Stage 3B indicates that production and stockpiling are underway.

DECLASSIFIED
SECRET
DOE/OC
NLOA

[redacted]

The 1950 program, listing 16 categories of research and 22 categories of specific weapons projects, also reflected the President's decision that development of a thermonuclear weapon would be pushed. The LASL plan for 1950 noted:

> "The program proposed ... appears to LASL to be almost the maximum possible effort in the direction of understanding and attaining thermonuclear reactions and, at the same time, to maintain progress in ... fission weapons sufficient to play a real role in the short-range position in this country .... It must also be clear that the general nature and philosophy of the thermonuclear program will differ from those heretofore employed by Los Alamos in its study of fission weapons. Because of experimental and theoretical necessity, and in an attempt to gamble on the chance of maximum progress, tests at Eniwetok involving the expenditure of sizable amounts of fissionable material will take the place of part of the heretofore extensive model testing and detailed theoretical calculation. The more empirical approach can, with great good luck, materially shorten a development period; on the other hand, the chance of failure in such tests will be appreciably higher than that under the old philosophy."

In March 1950, LASL initiated an accelerated program under which most of LASL personnel worked a six-day week through 1951.

By Spring 1951, LASL had perfected an experiment to determine if a fission bomb would generate enough heat to initiate a thermonuclear reaction in liquefied materials. A Greenhouse series test demonstrated the validity of this approach.

Almost immediately following Greenhouse, LASL began development of an experimental device for a large scale thermonuclear detonation or reaction. Perfection of this device required extensive engineering assistance on the device itself by American Car & Foundry Company, and extensive cryogenics assistance by three groups. National Bureau of Standards, in the AEC-built Cryogenics Engineering Laboratory at Boulder, provided engineering research and produced materials required; Cambridge Corporation developed and provided means of transporting the liquids; and Herrick Johnston engineered and built a liquefaction plant on Parry Island. The device was tested in the Fall of 1952, during Operation Ivy.

On the basis of Ivy results and other basic design determinations, shortly after the test there was initiated a comprehensive program for development of DELETED

DELETED

In addition to the three weapons for early test and military use, LASL was developing in mid-1953 other experimental devices to prove new concepts of design. (Other developmental work was also underway after June 1952, in the new Livermore Laboratory.)

Stockpile Operations and Problems ALOO

One of the primary objectives of all SFO operations is the stockpiling of atomic weapons in accord with broad directive schedules and military requirements as these are formulated and issued from time to time by higher authority.

[redacted]

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[redacted]

Working Relations with DOD

An inspection liaison section had been assigned for the purposes of review and recommendation relative to the DOD interest in specifications and inspection. This section is comprised of military officers who review the specifications presented by Sandia Corporation for AEC approval. The arrangement affords the field office a single point of contact on matters of inspection and specifications wherein coordination with DOD is desired or required.

In the administration of AEC site inspection activities, members of SFOO make periodic liaison visits to ZI sites. Site commanders and staff level officers have assisted the AEC inspection program as requested and/or required.

Distribution of War Reserve Material

On July 1, 1950, the production of War Reserve Material was restricted to Sandia Corporation and Burlington, producing only one type of weapon at any one time. The distribution of the material was to Sites Able, Baker, and Charlie. At that time the distribution was performed by one person in the custodial unit of AEC-Sandia. The material was shipped direct from production immediately in order to build up the stockpile as quickly as possible. This was done primarily to meet military requirements and maximum loads; nearest destination was a secondary consideration.

As this operation progressed through 1951, 1952, and 1953, there were several different types of weapons developed; producers increased from two to four, and sites increased from three to nine, consequently, by 1953, the distribution of War Reserve Material developed into a network system of producers, sites, types of weapons and components, which resulted in a centralized distribution point in order to coordinate the production and shipment of the various weapons and their components to the sites in proper ratio to assure the availability of complete weapons.

This centralized distribution point was reorganized in June 1953, into the Administrative Branch of the field office, and it was necessary to reassign personnel in order to perform this function. This was accomplished by changing the duties of certain personnel in the Branch in order that part time could be spent in the performance of this function.

14. NUCLEAR FIELD TEST OPERATIONS

Testing goes hand in hand with each step in the manufacturing process, from research to stockpile. Laboratory testing is continuous, including, for instance, the tests of the behavior of metals at extreme low temperatures conducted at the Boulder Cryogenics Laboratory in recent years.

ALOO

Both Los Alamos and Sandia have extensive and specialized programs of field testing which do not involve full-scale nuclear detonations. Sandia has its own backyard testing laboratory in the Sandia Base area, a test site at Salton Sea, and uses many other testing sites throughout the United States. These, as discussed previously, range from ballistic, vibration, and static load tests to catapulting and arresting tests, aircraft compatibility, and drop tests of non-nuclear over-all weapons. One of the major reasons for locating Los Alamos Scientific Laboratory on an isolated New Mexico plateau was sparse population and adequate real estate for explosive, but not full-scale nuclear, tests. Several outlying

[redacted]

sites have been used routinely by LASL since 1943 for tests involving high explosives and for tests involving radioactive materials. As discussed in the previous section, much of the requisite knowledge up to the point of disassembly of implosion-type weapons could be tested at Los Alamos' outlying sites. With the advent of two-stage thermonuclear experimentation, however, Los Alamos' outlying sites could no longer be used to acquire assembly knowledge; exploration of both the assembly and disassembly phases now require full-scale field tests.

A majority of full-scale field tests is for exploration of what takes place during assembly and disassembly and for nuclear components research and development. Some are held, however, to check the functioning of various components or of the full weapon. Tests for these purposes are utilized additionally by other national programs, such as military and civil defense effects programs. On occasion, tests are scheduled almost entirely to meet military requirements, but are then used additionally for developmental research.

From the viewpoint of AEC programs, full-scale nuclear field tests are held for the following reasons: To

1. Assure the adequacy of a device or weapon before it enters the national stockpile, to provide a firm basis for undertaking the extensive engineering and fabrication effort which must be expended in order to carry a preliminary model to the version satisfactory for stockpile production.

2. Demonstrate the adequacy, or inadequacy and limitations, of current theoretical approaches in order that promising avenues of development may be exploited more fully or given lower priority of attention.

3. Explore phenomena which can vitally affect the efficiency and performance of an atomic weapon, but which are not susceptible to prior theoretical analysis of sufficient certainty.

4. Provide a basis for choice among existing theoretical methods of weapon improvement in order to concentrate attention along lines of the greatest practical significance.

5. Determine the validity of entirely new and untried principles proposed for application to the production of explosive atomic energy at improved efficiency.

6. Provide entirely new information pertinent to weapons development arising as a by-product of scientific observation of full-scale detonations. Experience has shown the significant value of such incidental information obtained in addition to specifically planned objectives.

7. Gain time in urgent development programs by the substitution of full-scale tests for a portion of a possible but lengthy calculational and experimental program in the laboratory.

ALOO

8. Provide, as a by-product, basic scientific information which becomes a part of the backlog of knowledge more normally obtained in the laboratory. Tests thus contribute to other major phases of weapons development. Another application of this type of information lies in its use in the interpretation from

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[redacted]

studies of bomb debris of the constitution and efficiency of nuclear devices detonated by other nations.

Nuclear field tests are thus important and integral factors in the diagnostic phases of the over-all weapons research and development program. They are also essential in providing the National Military Establishment and Federal Civil Defense Administration with pertinent information on effects, and for training purposes of many kinds. The activation of an overseas and a continental proving grounds, and the progressing frequency and number of tests, are a direct reflection of the rapid development of atomic weapons during the period.

Overseas Tests: Pacific Proving Grounds

During the pre-1947 MED period, the first nuclear device was detonated in July 1945, on a remote section of the Alamogordo (New Mexico) Bombing Range. This first, historic test was followed by Operation Crossroads, conducted in July 1946 at Bikini Atoll in the Marshall Islands of the Pacific. The operation consisted of two tests made to determine the effects of atomic weapons against naval vessels. As early as 1947, when the necessity for more tests was apparent, some consideration was given to selecting a testing site within the continental United States. Due to several deterrent factors, the decision was made to continue using the Marshall Islands.

Accordingly, Eniwetok Atoll in the Marshall Islands was approved by the President of the United States on December 2, 1947, as the site for an atomic proving ground entrusted to the AEC for operation and maintenance. Its isolated location and more usable real estate influenced its choice over Bikini. Three devices were tested during Operation Sandstone in April 1948. As a result of the Sandstone tests, the efficiency and flexibility of atomic weapons were substantially increased. Construction of permanent facilities on Eniwetok and Parry Islands began immediately after the operation, and the Pacific Proving Grounds during the present period has served as the overseas site for two series of full-scale tests.

Operation Greenhouse -- Was conducted during April and May 1951. The series consisted of four tests: the detonation of two nuclear weapons (bombs) and two experimental devices. The first shot, a weapon test, was detonated April 8 on a 300-foot tower on Runit Island, Eniwetok Atoll. The second shot, also a weapon test, was detonated April 21 on a 300-foot tower on Engebi Island. The third shot, a device test, was detonated May 9 on a 200-foot, heavy-load tower, on Eberiru Island. The concluding shot, also a device, was fired on a 200-foot tower on Engebi Island, May 25. The objectives of the operation were to prove: a weapon of higher yield and efficiency, a weapon of smaller size and weight, and to conduct explorations in the thermonuclear field. In addition, eight experimental programs to study the effects of nuclear detonations on structures, equipment, materiel, and animals were included for the benefit of DOD, AEC Division of Biology and Medicine, and FCDA. Long range detection techniques were further studied during the operation.

ALOO

Operation Ivy -- Planning was already under way when Greenhouse was concluded. The series was announced on October 1, 1951. The Ivy series consisted of the detonation of a very high yield thermonuclear device, and a high yield nuclear weapon. The first shot was detonated on November 1, 1952, from a surface platform on Elugelab Island. The second shot was an air-dropped weapon detonated at a height of 1,500 feet over Runit Island on November 16, 1952. The test contributed significantly to work in the thermonuclear field. Eleven experimental programs were also included in the Operation.

[redacted]

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Eniman Camp - Bikini Atoll
from Lagoon Side



4500-foot Airstrip at Bikini Atoll
Constructed on Two Islands with
Connecting Causeway

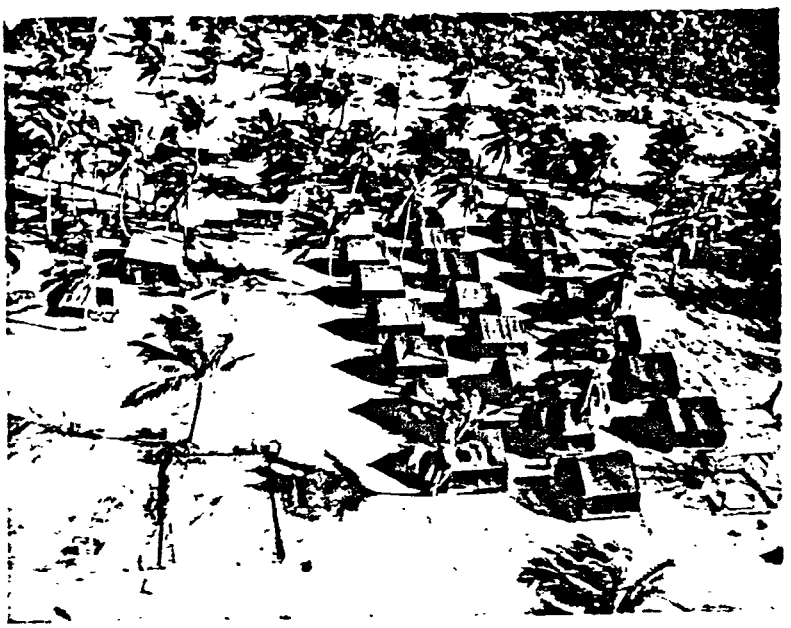


Portion of Parry Island

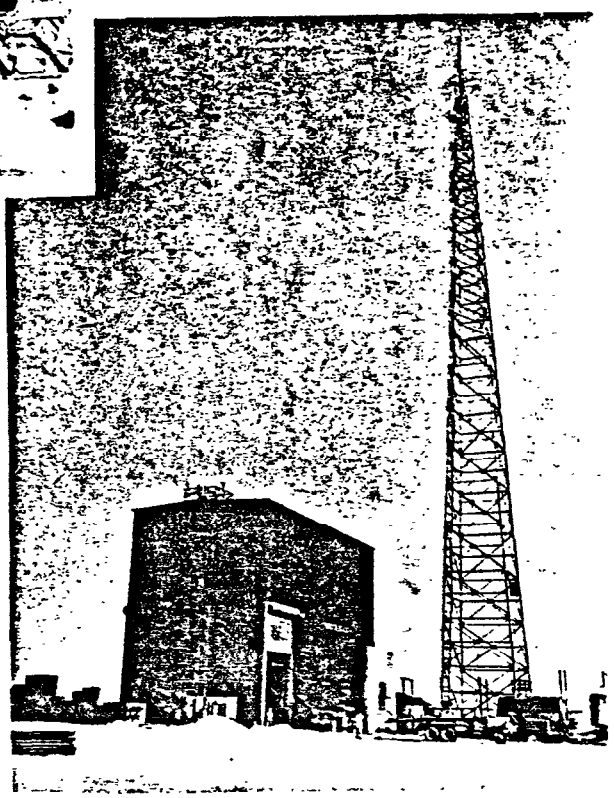
DOE/ALO

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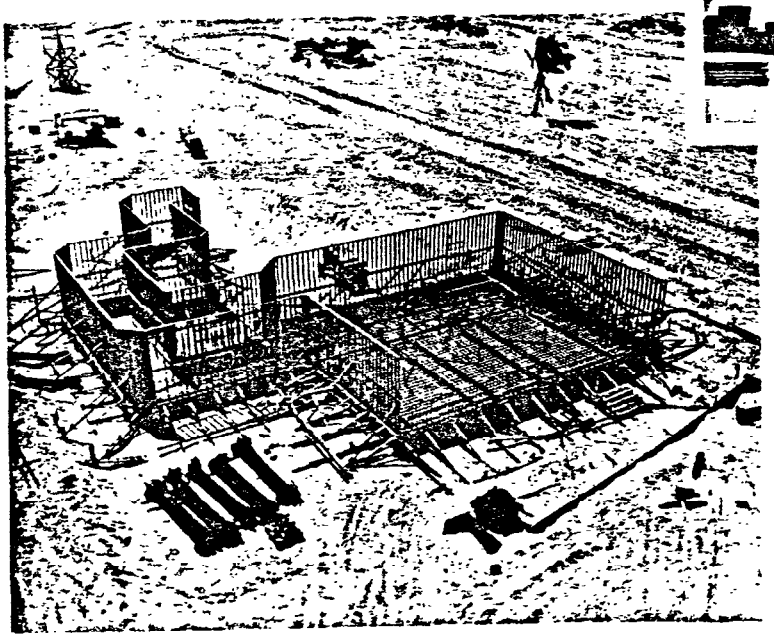
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Beach-head Camp at
Bikini (on Enyu Island)



Zero, Site Elugelab and
Telemetering Tower



AL00

Bogon, Reinforced Concrete
Recorder Station

Continental Tests: Nevada Proving Grounds

As early as 1947, LASL had proposed that AEC activate a continental test site. It was recognized, however, that continental operations would pose difficult problems, including protection of sensitive information, public safety, and public reaction. It was determined that Operation Sandstone would be held overseas and the question of a continental site was postponed.

More frequent tests became essential during 1949 and 1950. LASL required testing at a rate which could not be satisfied overseas. A related test preliminary to Operation Greenhouse was required in 1950 and, with the outbreak of Korean hostilities, LASL renewed its request for a continental site. Studies and site surveys had continued throughout 1948-1950. It was generally agreed that continental tests would be economical of time, manpower, and money. It was finally agreed that, under feasible controls, tests of devices of limited yield could be held with adequate assurance of public safety. Abandonment of Pacific Proving Grounds was never considered, although the possibility that the overseas area might be closed by the international situation was a factor considered. The projected continental site was to be in addition to the overseas test site.

On November 14, 1950, a memorandum from the National Security Council to the Secretary of State, Secretary of Defense, and the Chairman of the Atomic Energy Commission, notified them that the President had directed the Commission, with the assistance of the Department of Defense, to survey suitable continental sites and to recommend one for early development and use.

Five possible areas had been surveyed and the results were re-evaluated:

The Alamogordo-White Sands Guided Missile Range in New Mexico.

The Dugway Proving Ground, Wendover Bombing Range in Utah.

The Tonopah-Las Vegas Bombing and Aerial Gunnery Range in Nevada.

An area in Nevada about 50 miles wide, and extending from Fallon to Eureka.

The Pimlico Sound, Camp Lejeune Area, in North Carolina.

Selection of these possible sites followed elimination of sites in Canada and Alaska; sites along the northeastern coast; and other sites along the southeastern seaboard. Sites in the arid west seemed desirable because they were sufficiently remote from population, and had sufficient surrounding uninhabited areas to allow conduct of nuclear tests with adequate public safety.

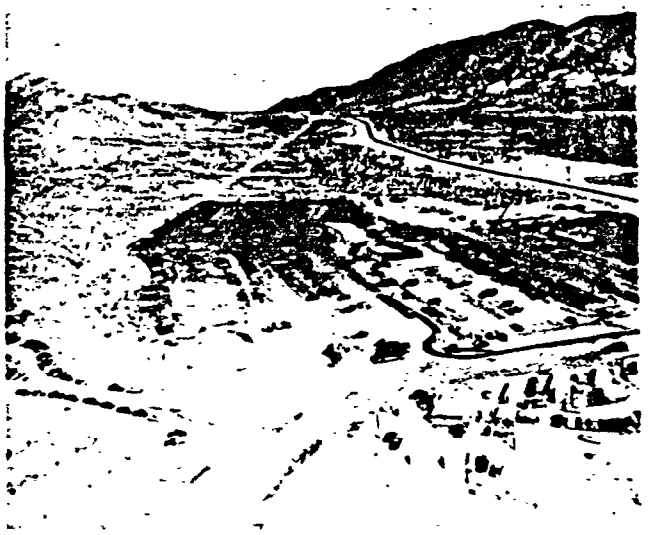
Only the Las Vegas area met the criteria for a continental test site: ready accessibility to Los Alamos Scientific Laboratory and Sandia Laboratory by land and air, good communications, adequate radiological safety for small off-site population, satisfactory weather, reasonably regular topography, prospects of economy of preparation and operation, and sufficient real estate.

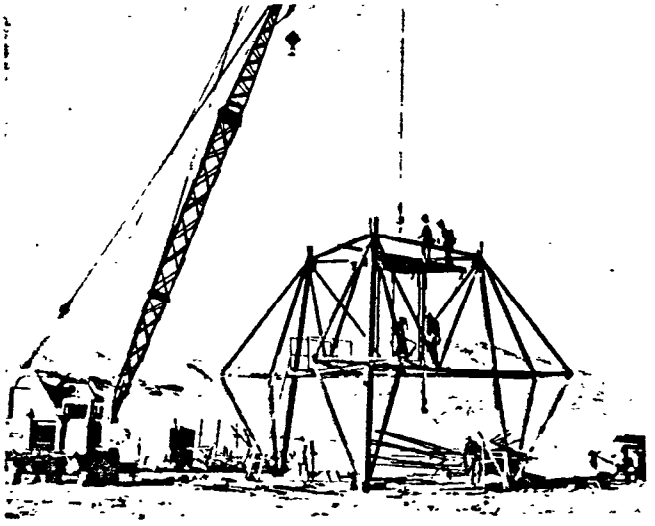
ALOO

On December 13, 1950, the Chairman, AEC, submitted recommendations for use of the Las Vegas Bombing and Gunnery Range as an atomic continental test site to a Special

DOE/NE

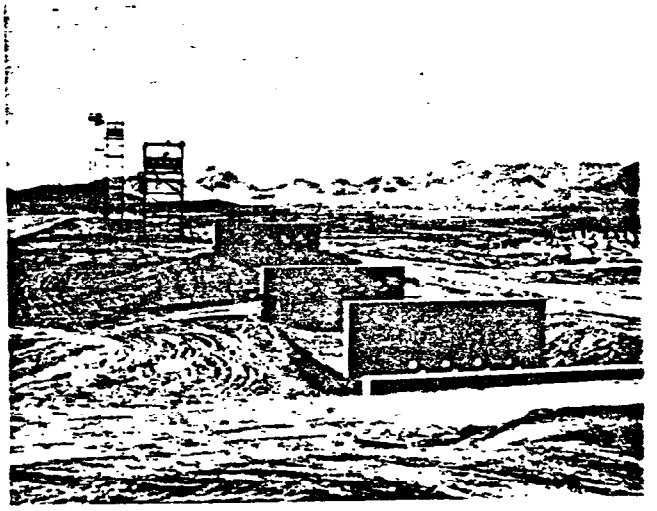
Camp Mercury, during Construction
Nevada Proving Grounds



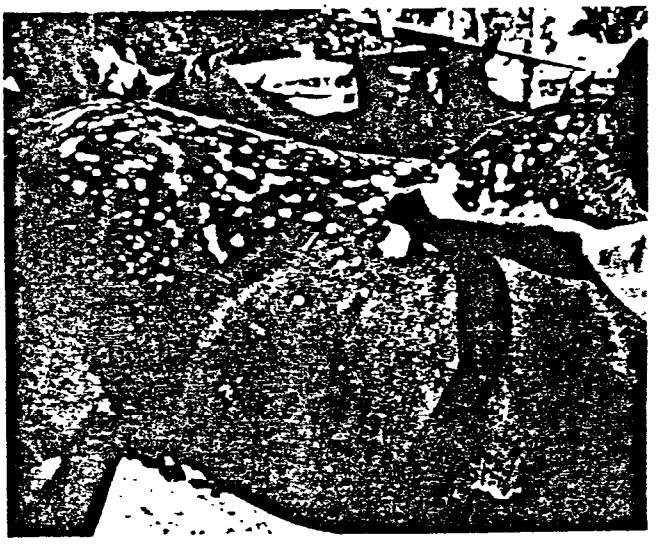


Tower Construction, Forward Area,
Nevada Proving Grounds

Tower Construction, Forward Area,
Nevada Proving Grounds



ALOO



Horses Injured by Radiological Fallout near
NPG during Upshot-Knothole

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Committee of the National Security Council for Atomic Energy Matters. Five days later Presidential approval was given, and preparations were made to activate the site which subsequently became Nevada Proving Grounds.

Continental Test Operations

The Nevada Proving Grounds was activated January 1, 1951, using temporary construction and the first nuclear test shot was detonated on January 27, 1951. During the current three-year period, four series of continental tests have been conducted:

Winter 1951 Series (Operation Ranger)—five shots. All were experimental devices tested by the air drop technique. The tests were diagnostic in nature.

Fall 1951 Series (Buster-Jangle)—seven shots. Five were primarily diagnostic for the benefit of LASL, and two were primarily of interest to DOD as weapons effects experiments. Shot 1 was a tower shot, the following four were air bursts, and the last two were respectively a surface and an underground burst.

Spring 1952 Series (Tumbler-Snapper)—eight shots. They were equally divided as to air bursts and tower shots; five were experimental devices of primary interest to LASL, and three were sponsored by DOD in connection with weapons effects phenomena.

Spring 1953 Series (Upshot-Knothole)—eleven shots, including air, tower, and the 280mm nuclear projectile shot. Nine shots were diagnostic in nature, seven being of primary interest to LASL and two to UCRL; and two tests were of primary concern to DOD, including proof-testing of the 280mm nuclear projectile. The latter, however, was of particular interest to LASL, and justification for the shot was a joint AEC-DOD responsibility.

During the last three series approximately 37,500 personnel of the Armed Forces, including Army, Air Force, and Marine Corps units, were indoctrinated in the principles of atomic warfare through simulated combat maneuvers conducted in conjunction with the tests. Armed Forces participation, "Exercise Desert Rock" I-V, was conducted by the Sixth Army from a headquarters at Camp Desert Rock nearby. Various groups of officer volunteers during several shots were stationed in advance of the main body of troops at the time of detonation. Also exposed to detonation for Armed Forces effects information were materiel and supplies, above- and below-ground structures, and items such as pine trees and railroad equipment.

Air Force participation for crew indoctrination and experimental test purposes as well as for normal air support—such as cloud tracking and sampling—was equally heavy, particularly in the last series. During Shot 9 (1953 series) a maximum of 100 aircraft participated.

Notable from a public relations viewpoint were the two "Open Shots" of April 22, 1952, and March 17, 1953, during which national news media representatives, public officials, and Federal Civil Defense Administration representatives were permitted, under security control conditions, to witness the detonations as uncleared observers. The resulting wide coverage through all media—press, periodical, radio, TV, and motion picture—provided the public with opportunity to add to its understanding of Commission and of Armed Forces activities and objectives. Federal Civil Defense Administration participation in effects experiments was continued throughout the last series, and was reportedly of great value in the national defense effort.

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15. CONTROL OF INFORMATION

Control of information on the development and utilization of atomic energy is one of the basic AEC missions under the Atomic Energy Act of 1946. The various related provisions of the Act are defined and interpreted in GM-INF-2, "Policy for Control of Information." Both of these basic papers state firmly that critical information must be protected and then, recognizing the value of the free exchange of ideas and criticisms and the dangers of security blanketing, they state as firmly that non-critical information must be made available to the public. An unusual provision of the Act, Section 3 (a), underlines this by providing that research and development contractual arrangements "shall not contain any provisions or conditions which prevent the dissemination of scientific or technical information, except to the extent such dissemination is prohibited by law."

Four distinct programs have been developed which support the information control objective. Two have as their primary function the protection of classified information (in the sense of all data): Classification and Security. Two have as their primary function assuring that non-critical information is made publicly available: Declassification and Information.

Responsibility and authority for the control of information programs is assigned by the Commission to the General Manager and by him to Operations Managers, these assignments being all-inclusive as part of in-line management except as specifically limited in official papers. Operations Managers may in turn delegate more limited responsibility and authority to their field offices and to contractors.

Washington staff supervision has been assigned by the General Manager to: Office of Classification (including its Declassification Branch), Office of Security, and Division of Information Services. Each has a counterpart, either fulltime or added duty, performing staff supervision in SFOO headquarters and each has a counterpart or is reflected in field offices and contractors.

Summary of SFO's Information Control Programs

Four programs of SFO are concerned directly with the control of information:

The mission of SFO Classification is to determine the weapons information which could be used by inimical interests to the detriment of United States security, and as part of the same process to establish the data which may remain unclassified. A continuing review of both categories is performed to determine if developments require protection for previously-unclassified items, or if protected items may be downgraded to lower classifications or should be considered for declassification.

A primary mission of SFO Security is to protect classified weapons information, assuring that unauthorized persons do not have access to critical data. A related objective is to assure that security fences are not put around unclassified information. The mission goal is expressed in a variety of operations, such as personnel clearance and control, document control, visitor control, and protection of physical property including fissionable materials.

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The mission of SFO Declassification is to determine if and when previously-protected weapons information may be published without adversely affecting the nation's security. The original mission related only to the declassification of Restricted Data. The present assignment includes, however, declassification action on all categories of classification and has been extended by Washington directive to include some measure of control over photography which is unclassified or over photography in which the Military may have an interest.

The mission of SFO Information is also dual: To withhold classified weapons information from unauthorized persons while encouraging and facilitating the dissemination of non-classified information generally and of classified information to authorized persons to advance the national welfare and satisfy the national interest. Because it is the sole program concerned with putting out material, the balance between Information's two operating objectives should favor dissemination. This balance has seesawed during the past three years with progressive withdrawals of field authority on release of unclassified information while requirements for dissemination were multiplying.

The nature of the weapons manufacturing mission requires that all four programs be conducted in intimate association with the Armed Forces and, to some extent, with other Federal agencies. The four programs' functions are such that they cannot be operated as a fully-delegated field activity; they require detailed, day-to-day coordination with like program divisions in the AEC headquarters. Likewise, the functions may not be fully delegated to field offices and to contractors, requiring detailed, day-to-day coordination between SFOO and its field operators.

It is of interest to note that two of the programs and a major phase of a third are almost exclusively contractor operations. Classification and Declassification are represented at the SFOO staff level and in the field by contractor personnel. Control and dissemination of scientific and technical information is almost exclusively a contractor operation, although some phases of the public release of such information are conducted by the SFOO Information Division and by field offices.

There has been little basic change since mid-1950 in the mission functions of the four programs, Security having perhaps changed most through a searching re-evaluation and clarification of its objectives.

In keeping with the rest of SFO, the requirements—the workload and scope and geography—have been expanded materially.

The all-essential goals common to the four programs are to segregate and to protect critical information and to segregate and encourage dissemination of the non-classified information. During 1947-1950, Classification and Declassification progressed measurably toward information control goals, resulting in a considerable accomplishment in the realistic protection and dissemination of scientific and technical information. Security and Information lagged somewhat in 1950 with too much non-classified material and information being withheld or protected.

AL00

The primary achievement in SFO control of information during the past three years has perhaps been the development of understanding within all four programs of the duality of mission and an integration of attitude and effort. The result has been a sharper definition and a narrower total area requiring protection, permitting better protection. The result has also been a much broader area which did not require the costs and effort of

protection and which could be released safely. The effect on information released publicly has been especially noticeable in the continental test activity, but it has been just as real throughout the research, development, production, community and other management structure of SFO.

Classification

Santa Fe Operations, having the major field responsibility within the AEC for the weapons mission, originates a large volume of data requiring classification. The scope of the activity is indicated by the fact that more than 1,500 formal, written decisions were rendered by the SFO Classification Board during the past three years, and by the Security report that 15,000,000 classified documents have been originated within SFO each year.

In the period since mid-1950, the SFO classification organization has been decentralized to some extent and at the same time formalized as a SFO-wide activity. The position of Dr. Norris E. Bradbury, Director, LASL, as the staff Classification Representative for the Manager, SFO, was made formal and shown on organization charts. Dr. Bradbury serves as Director of the SFO Classification Board with Dr. Ralph Carlisle Smith, Assistant Director for Classification and Security, LASL, as his executive officer in both capacities.

The Manager, SFO, arranged for the appointment of a local classification board at Sandia Laboratory. As a result, the SFO Classification organization as of July 1, 1953, included:

a. The SFO staff Classification Representative: Dr. Bradbury, with Dr. Smith as his executive.

b. The SFO Classification Board: Dr. Bradbury, Director; Dr. Smith, Executive Secretary; and special panels serving as members according to the nature of matters to be considered.

c. The Los Alamos Scientific Laboratory Classification Board: Same as above.

d. The Sandia Laboratory Classification Board: J. R. Townsend, Chairman; William H. Lawrence, Secretary.

Consideration is being given to establishing like boards in other contractor and field office organizations.

Decisions of the local area boards are submitted to the SFO Classification Board for information, or for review and final determination. For uniformity of classification policy and interpretation of existing guides, the SFO Board is the final authority within SFO on all classification matters subject to SFO determination. By this interchange of decisions, the boards have established a more uniform policy and have minimized possible compromises of information. The practice has proved especially valuable in control of information relative to the various high explosives processing plants within SFO.

AL03

A major activity has been providing guidance to the new contractors who have entered into the program including: Dow Chemical, National Bureau of Standards, Procter & Gamble, Thompson Products, Cambridge Corporation, American Car & Foundry, etc.

In his capacity as SFO Classification Executive, Dr. Ralph Carlisle Smith has acted as the classification officer for all weapons test operations, including Operations Greenhouse,

[redacted]

Ivy, Ranger, Buster-Jangle, Tumbler-Snapper, and Upshot-Knothole. In Operation Ivy and the forthcoming Castle, he has been designated not only as classification representative for the AEC but also for the Armed Forces, serving on the staff of the Joint Task Force Commander. In this manner it has been possible to maintain a rather uniform classification policy throughout the weapons and weapons test programs.

Within SFO, a series of classification guides for the several weapons test organizations has been prepared, all of which guides have been approved by the Armed Forces and the AEC. In addition, a few specific guides have been prepared for certain of the contractors because of the peculiar problems involved. These special guides cannot be incorporated entirely within a general guide for the AEC because they take into consideration peculiar circumstances particularly associated with the contractor.

The office of SFO classification representative has maintained detailed and almost continuous contact with the AEC Office of Classification in the preparation of a revised AEC-DOD Classification Guide, a General Classification Guide, a Critical Materials Classification Guide, and in the interpretation of data related to apparent compromise of information.

The Nuclear Weapons Classification Subcommittee, organized mainly of SFO personnel under the leadership of Dr. Alvin C. Graves, has made two major recommendations on information classification which, if adopted, would materially assist SFO activities and result in reduced security costs and no loss or weakening of national security. The first of these is classification recognition that there is no security involved in the approximate yield of nuclear detonations within the continental limits. It is not proposed that these yields should be publicly announced, but that no information should be classified merely because it gives an approximation of such yields. The second recommendation is to adapt to the nuclear weapon program a principle which has been adopted in the reactor field and is now identified as the "black box" idea. This is especially applied to those items of the nuclear weapon which are clearly of a military nature and not essentially an AEC matter, such as the ballistic case and fuzing system for nuclear weapons and the outer case of an aerial bomb, guided missile, artillery projectile, and the like.

Declassification

Dr. Norris E. Bradbury, Director, LASL, in his capacity as Coordinating Organization Director for all activities within SFO, is in direct charge of the SFO Declassification program. Dr. Ralph Carlisle Smith, LASL, is his Executive Officer for declassification.

There is no field organization as such. The individual, contractor, or AEC unit proposing declassification of a report or other material routes it to the Coordinating Organization Director. Field Classification Boards usually provide an advisory opinion to reflect thinking in the operational area immediately concerned.

AL00

The Coordinating Organization Director is advised by Responsible Reviewers, recommended by the Manager, SFO, and appointed by the General Manager, AEC. One member of the LASL staff is also a Senior Reviewer for the AEC and assists on SFO matters as required. Responsible Reviewers are recognized authorities in their respective fields and review documents submitted for declassification which fall within their fields of specialization. Appointment in the 1950-1953 period of Responsible Reviewers at Sandia Laboratory recognized that the work of that laboratory was sufficiently specialized to require specially-trained reviewers in order to expedite the declassification review of specific documents.

[redacted]

To maintain a uniform policy to avoid compromise of program information through declassification of several separate but related items by different organizations, the Director, LASL, and his staff continue to be the channel for forwarding material to AEC Declassification Branch for final action.

During the last three years, there has been a considerable increase in the number of technical items considered for release by Sandia Laboratory. Many of these items have been processed as declassifiable scientific information but might readily fall within the more recent Industrial Information program.

With the policy of classification boards at various field installations, there has been a lesser tendency to overclassify with subsequent declassification required. However, there has been a continuing program to review previously-issued material for downgrading or declassification.

In the three-year period of this report it is estimated that there has been formal declassification on approximately 585 items from LASL and 16 items from Sandia Laboratory. In addition, 34 Los Alamos items have been reduced to Official Use Only. There have not been many items for formal declassification from the other SFO contractors, but it is anticipated that in the future, particularly in view of the Industrial Information program, there will be a sizable quantity of items from them.

The publication of "The Effects of Atomic Weapons" by the Los Alamos Scientific Laboratory early in 1950 and the release of information involved in the Rosenberg-Greenglass cases has made it feasible to consider for public release many items previously considered classified. However, it is recognized fully that on the newer developments the classification of the information might be even stricter than that applied to the wartime and immediately postwar data.

Security

The report of the Office of Security operation is presented separately later in this chapter.

Public and Technical Information

Staff supervision and certain operating functions at the headquarters and the national levels are assigned by the General Manager to the Division of Information Services. Basic assignment in GM-O&M-23, Serial 107, April 24, 1950, is still applicable although there have been various changes not yet formalized in a GM. Organization Chart, DIS, January 21, 1952, is the most recent expression of functions and supporting activities, although it is not current. Similar assignment of both staff supervision and of operating functions, and of supporting activities, prevails in Operations Offices.

ALO9

By organizational division at the Washington level, there are two formal supporting programs: Technical Information and Public Information. Technical Information is concerned with the preparation and official dissemination of classified information and with preparing, controlling, and making publicly available to specialized audiences non-classified scientific, technical and industrial (including management) information; with the industrial (or technological) activity actually being a separate sub-program placed under Technical Information. Public Information is concerned with the controlled public release of scientific, technical, and general information.

DOE/AO

[redacted]

[redacted]

SFO activity encompasses both programs, and through assignments to the SFOO Information Division extends further to sub-programs such as internal information and special projects. Responsibility for staff supervision and for the essential SFOO-level operations are divided between the Director, Information Division, SFOO, and the Assistant Director, LASL, serving essentially as Technical Information Officer for SFOO. Both programs are supported by added duty personnel in field offices and contractor organizations, and by technical or other information personnel in the two weapons laboratories.

The Technical Information Program

This is almost exclusively a contractor activity and one which is presently conducted almost entirely by Los Alamos and Sandia laboratories. Primarily because of its close relationship with declassification procedures, the staff supervision function is performed by LASL's Assistant Director. SFOO Information Division is responsible only for maintaining a degree of awareness of the activity.

Classified Information -- There is a large volume of classified scientific and technical papers and of reports which are distributed throughout the AEC and to some extent to DOD, FCDA, U. S. Weather Bureau, U. S. Public Health Service, etc. The service provided includes: Preparation, coordination and review, and dissemination; and provision of library, document control, and bibliographical services.

Within the Los Alamos Scientific Laboratory there has been an increased effort to put more of its reports into a form so that they will not contain critical weapon data and may be distributed more widely through the AEC classified projects. Title lists of the reports are included with the Laboratory Monthly Report and receive substantial distribution directly to several Armed Forces headquarters. There has been established in LASL a Weapons Test Report Office as a service group for continental and overseas test organizations to provide centralized, expeditious, and uniform handling of weapon test reports. Before this was done, each Joint Task Force had set up a group for handling the reports of its individual operation. Arrangements have been made with the Oak Ridge Extension of Division of Information Services for routine editorial and reproduction services, thus removing the load of reproduction from various field groups and reducing the cost of reproduction of reports through the Government Printing Office. This was accomplished when the workload of the National Nuclear Energy Series was removed from the Oak Ridge extension. It is understood that this avoided the disbanding of an effective organization. About 275 weapons test reports were issued prior to mid-1953.

Sandia Laboratory distributes its reports to a substantial extent within the Department of Defense, such dissemination being facilitated by the close liaison between Sandia and Field Command, AFSWP. The technical reports published by Sandia Corporation cover two broad areas of activity which are conveniently separated into reports covering the development of new weapons, and reports, more properly called manuals, covering storage and use of stockpile weapons.

ALOO

Development reports are prepared by the design groups. There is a series of reports for each development program. The series begins normally with a feasibility study report, which is followed in a normal program by a proposed ordnance characteristic report. The series includes a number of design status reports, culminating in a report entitled "Design Status at Design Release." The final development report is a weapon evaluation report, normally published some months after design release and late enough in the development program to permit a complete evaluation of the weapon's performance and capabilities.

[redacted]

[redacted]

While development reports are written for both the AEC and the DOD, the manuals for stockpile weapons are prepared primarily for the weapon users, the DOD. They include manuals of weapons, weapon assemblies, fuze tests, aircraft loading tests, surveillance, aircraft modification, and handling equipment, assembly and maintenance. They include not only manuals for the assembly, inspection, storage, and use of atomic weapons, but also manuals which serve as catalogs of information and miscellaneous indexes of publication. This large second group of reports is prepared by those most closely in touch with the actual users of the weapons in the field, the military liaison and training organization. The manuals are prepared in close coordination with the groups who train teams to use weapons in the field and with the field engineers of this organization. In this way the manuals' writers are aware of problems which arise in the field and are in a good position to modify manuals rapidly in accordance with changes suggested by field experience.

In both of the large areas of publication, the development schedules and the need for up-to-the-minute information place a premium on meeting tight deadlines.

Other SFO contractors deal almost exclusively with weapons information and hence do not distribute their reports as widely within the AEC organization.

Declassified or Unclassified Technical Information -- The AEC program on non-classified scientific and technical information is primarily not one of public dissemination, but is one of facilitating an individual's dissemination to specialized audiences and of making information available to anyone interested.

Unclassified reports are distributed according to Technical Information Division directive 4500 "Distribution Lists for Non-Classified Reports."

The need to make atomic energy technological information available to American industry was recognized in 1952 with establishment within Technical Information Service in Washington of an Industrial Information Branch. This new sub-program acts primarily to stimulate field organization dissemination of the subject information. It varies from other contractor-operated phases of technical information by assigning final coordination and clearance responsibility within an Operations Office to the AEC information officer. Of the contractors other than LASL and Sandia, Holmes & Narver, support service contractors for Pacific Proving Grounds, has perhaps led in the preparation and dissemination of the industrial type information. The industrial program has not been fully activated within SFOO. It is anticipated that in future years more information now being processed along with scientific information will be separately identified. Three SFO representatives are members of the AEC-wide Industrial Information Committee: Richard G. Elliott, Director of Information, SFOO; Dr. Ralph Carlisle Smith, Assistant Director, LASL; and H. J. Wallis, Superintendent, Staff Services, Sandia Laboratory.

ALO9

In keeping with GM-CLA-2, "Classification Procedures for AEC Research Contractors," there is a continuing flow of information on unclassified areas of research. Specified off-site research requires no reference of information material to higher authority. Specified on-site research may be issued by scientific personnel concerned or published upon authorization by a Laboratory Director. SFOO, for instance, administers a contract with University of California at Los Angeles and the medical school's work is generally unclassified; its reports receive wide dissemination within the AEC and in journal articles.

Public dissemination may be through: an unclassified formal report; a paper in a scientific, professional, or trade journal; a paper with or without visual aids for presentation before a specialized group; etc.

SECRET UNCLASSIFIED

June 1967

RS 3434/10
ATOMIC WEAPON DATA
Mark 5-2

HISTORY OF THE EARLY THERMONUCLEAR WEAPONS (U)

Mks 14, 15, 16, 17, 24 and 29

SC-M-67-661

Redacted Version

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Information Research Division, 3434

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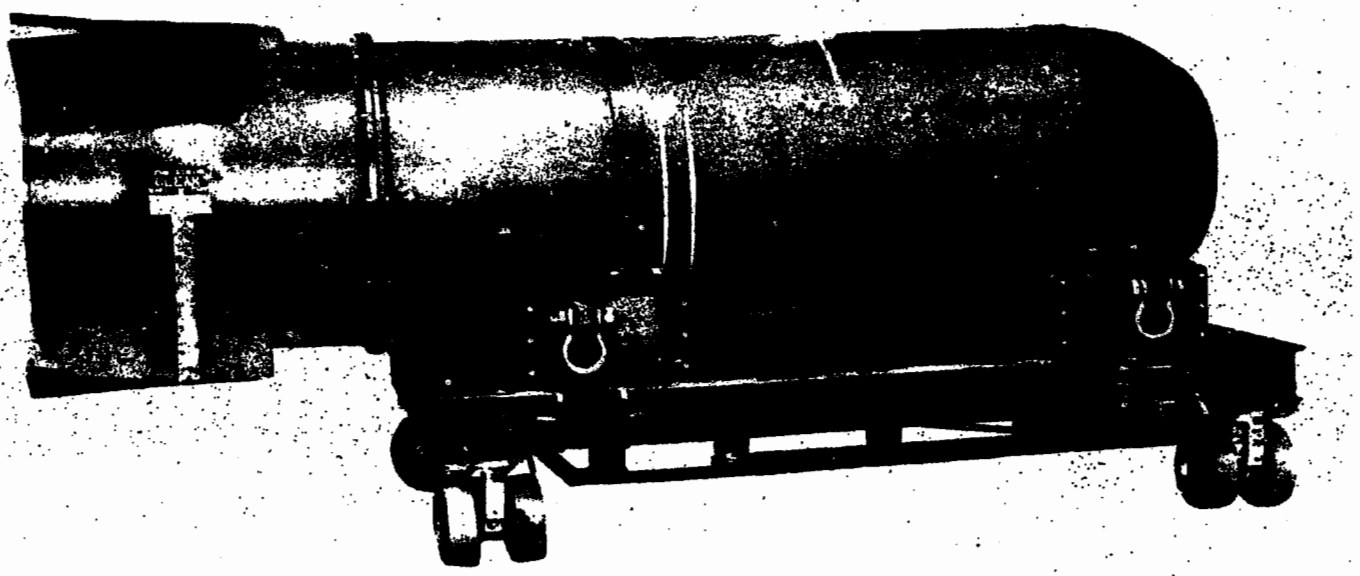
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Weapon on H-508

Mk 15 Bomb - Exterior View

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Timetable of Early Thermonuclear Weapons Events

Mk 14

Late 1920's	Discovery made that stellar energy is thermonuclear in character.
Early 1942	Discussion concerning theoretical possibility of starting a thermonuclear reaction with a fission bomb.
7/42	Basic nuclear studies of lightweight elements performed. Theory of "Runaway Super" bomb developed. Extensive work deferred due to press of effort on fission devices.
Postwar	Effort on thermonuclear studies deferred.
1947	"Alarm Clock" device proposed in place of "Super."
8/49	Russian atomic explosion announced.
1/31/50	President Truman directs that effort be continued on thermonuclear designs.
5/8/51	George shot of Operation Greenhouse demonstrates that deuterium and tritium can be made to fuse successfully.
6/19/51	Conference on thermonuclear theory held at the Institute for Advanced Study. (b)(1), (b)(3)
5/22/52	Sandia and Los Alamos propose guidelines for design of thermonuclear weapon to be called the TX-14; emergency-capability committee established.
6/13/52	Joint Chiefs of Staff establish requirement for thermonuclear weapons (b)(1), (b)(3)

9/15/52 Procurement for TX-14 program authorized.

(b)(1), (b)(3)

10/26/53 TX-Theta Committee formed, and holds initial meeting.

2/54 Emergency-capability TX-14's produced.

10/54 TX-14 Bombs retired.

Mk 15

11/28/52

(b)(1), (b)(3)

(b)(1), (b)(3)

4/23/53 Military Liaison Committee requests study of high-yield designs in the 30- to 45-inch-diameter range.

10/12/53 Los Alamos notifies Division of Military Application that TX-15 will be stockpiled by September 1955.

10/26/53

(b)(1), (b)(3)

11/13/53 Proposed military characteristics for TX-15 released by Field Command. Both bomb and warhead planned for production.

1/4/54

(b)(1), (b)(3)

(b)(1), (b)(3)

5/21/54	TX-Theta Committee suggests improvements to the Mod 0.
5/54	Emergency capability TX-17/24 Bombs stockpiled.
11/2/54	TX-17 parachute drop tests started.
11/54	All TX-17/24 emergency-capability units modernized to Mod 0 status.
12/54	Mk 17/24 Mod 1 design released, including inflight insertion mechanism for increased safety, fin of composite metal and plastic, and nuclear improvements.
3/55	Mk 17/24 Mod 1 Bombs enter stockpile.
6/1/55	Mk 17 Mod 2 design released, incorporating contact fuze.
9/55	All Mk 17/24 Mod 0 Bombs converted to Mk 17/24 Mod 1.
8/56	About 25 percent of Mk 17 stockpile converted to Mod 2. Mk 24 Mod 2 program canceled.
10/56	All Mk 24's retired in favor of Mk 36.
8/57	Mk 17 Bombs retired in favor of Mk 36.

hydrogen bomb should or should not be developed, the President directed the Atomic Energy Commission to continue its work on all forms of atomic weapons, including the so-called hydrogen or Super bomb. Work on Super was accordingly accelerated, only to be retarded again in mid-1950 when the outbreak of the Korean War re-emphasized the need for small nuclear devices.

The Air Force made early plans to carry and deliver large and heavy hydrogen bombs and, in 1950, established two projects, Brass Ring and Caucasian. Brass Ring envisioned carriage of the weapon in an unmanned drone B-47, which would be guided to a target by a mother ship and destroyed in the detonation. This project was given considerable support, due to uncertainty concerning the possible yield of a hydrogen bomb, then estimated to lie between 10 and 40 megatons. Project Caucasian involved the logistical support of a bomb containing large amounts of liquified deuterium at low temperatures.[7]

Los Alamos designed a device to test the rapidity with which a mixture of deuterium and tritium would fuse. This test, the Greenhouse George shot, was fired May 8, 1951.

(b)(3)

Edward Teller, one of the original backers of the thermonuclear weapon in 1942, and who had been working on the design in the intervening years, theorized that radiation energy had in some way compressed the deuterium-tritium gas, thus reducing its ignition point and increasing the efficiency of the reaction. This possibility was discussed at a conclave of scientists and AEC representatives June 19, 1951, and it was concluded by the attendees that a practical thermonuclear weapon was achievable, using radiation energy as a compressing force.

Due to some personal differences of opinion, Teller proposed the creation of a new physics laboratory to develop thermonuclear devices. He was supported in this stand by the Air Force, which offered to provide a suitable laboratory. Subsequently, the

AEC established a laboratory at Livermore, California, under the administration of the University of California. The contributions of the University of California Radiation Laboratory to the early development of thermonuclear weapons were somewhat meager, except that the existence of the laboratory helped to encourage the over-all program.

(b)(3)

The computational work involved in analyzing the thermonuclear process was a colossal task, and could not have been accomplished without the great advances in computing equipment that took place in the late 1940's and early 1950's. The IBM 601 was considered quite a machine in 1945, but it was far surpassed by the Maniac, designed at the Institute for Advanced Study, Princeton, New Jersey, and which became available in 1952. A problem that would require 3 months work by the 601 could be solved in 2 days by the Maniac. It is of record that, in the course of running a thermonuclear problem on the Princeton Maniac in 1953, the number of basic arithmetical computations performed was of the same order of magnitude as the total number of similar operations performed at Los Alamos (excluding those done on the Los Alamos Maniac) in the entire 10 years of operation of the Laboratory.

The first task assigned to the Los Alamos Maniac was to perform more exact and extensive calculations of the thermonuclear process.

(b)(1), (b)(3)

Sandia and Los Alamos forwarded a joint letter to the Division of Military Application May 22, 1952, proposing that the TX-14 be designed with the following guidelines:

had established a military requirement for the development of thermonuclear weapons with yields of 1 megaton and over, requesting that these weapons be compatible in size, shape and weight with delivery systems that would be available in 1954. Production facilities for thermonuclear materials would be developed immediately. It was felt that any prior production of a deliverable thermonuclear weapon by the Soviet Union would reduce the existing American lead in weaponry, and that such a shift in balance might well cause a change in Soviet policy. This factor alone provided adequate justification for an approach involving considerable technical risk and a large expenditure of funds.[11]

(b)(1), (b)(3)

Sandia would create a model, to be used in the solution of detailed design problems.[12]

(b)(3)

Some 30 grams of tritium were being produced per year at Hanford, and if all the piles were shifted to the production of this material, 60 grams per year could be turned out.

(b)(3)

thermonuclear weapons.[20] The work of the Committee assumed added importance from the start, as in the meantime the Soviet Union had announced August 12, 1953, that it had detonated a thermonuclear device.

(b)(1), (b)(3)

The capsule was manually placed in the insertion mechanism and cranked into position in the primary by a lever that extended from the nose of the bomb.

(b)(1), (b)(3)

(b)(1), (b)(3)

Meanwhile, other thermonuclear bomb designs had progressed to the point of stockpile entry. Since their yields, nuclear economics, assembly and logistics were better than those of the TX-14, the latter weapons were retired in October 1954.[21] Part of the retired material was used in the Mk 17/24 program.[22]

Mk 15/29

(b)(1), (b)(3)

The Military Liaison Committee wrote to the U. S. Atomic Energy Commission April 23, 1953, stating that the Department of Defense hoped to be able to deliver large-yield weapons by high-performance fighter-bombers and guided missiles.

(b)(1), (b)(3)

A weapon proposal was requested by September 1953, with the prospect of stockpiling any selected designs by late 1955. The Division of Military Application forwarded this letter to Los Alamos, noting that a preliminary statement concerning the TX-15 might help to clarify this design, which apparently had potentialities either as a tactical or strategic weapon, or both.[24]

(b)(1), (b)(3)

(b)(1), (b)(3)

Thus, parachute retardation was not necessary. However, since little would be saved by deleting the parachute, and the parachute might be required by other programs, the design was continued.[30]

A set of proposed military characteristics was released by Field Command November 13, 1953. Inasmuch as some thought had been given to the possibility of making the TX-15 compatible with the Air Force's long-range strategic missiles, such as REDSTONE and SNARK, both a TX-15 Bomb and an XW-15 Warhead were prescribed. Limiting parameters included a diameter of 35 inches, a length of 120 inches, and a weight of 6500 pounds.

The weapon would be required to withstand an altitude of 60,000 feet, temperatures from -65°F to +165°F, and an acceleration of ±10 gravities along the longitudinal axis. Automatic insertion and retraction of the primary capsule within a time cycle of 10 seconds would be possible at any time prior to release of the bomb, and during the missile trajectory except during high acceleration at launch or boost.

The TX-15 should be able to resist, without damage, any forces created by catapulted takeoffs, arrested landings, or normal flight maneuvers. The bomb would be capable of being dropped free fall and, if a high-drag shape was provided, consideration was to be given to the deletion of the drogue parachute.

The fuze should provide a safe-separation time and either air or surface burst.

(b)(1), (b)(3)

A surface burst should provide cleanup detonation in the event of failure of the air-burst fuze.

The ballistic properties of the bomb should be such that either free-fall or retarded trajectories would be predictable and reproducible. Releases were to be possible at all altitudes up to 60,000 feet and aircraft speeds of Mach 0.95. It

(b)(3)

The X-unit would be mounted on the forward face of the primary, and would be repackaged to fit into this space.

(b)(1), (b)(3)

The design of the TX-15 was accordingly accelerated and the TX-13 Bomb canceled.

The possibility of TX-15 missile compatibility was raised again in the March 26, 1954 meeting of the TX-Theta Committee. The SNARK was to be operational in early 1958, but could only carry a warhead weighing up to 7000 pounds. The G-26 NAVAHO would be available in late 1957 and could carry only 4000 pounds, but a G-38 follow-on NAVAHO, operational in 1960, would be able to carry 7800-pound warheads. The REDSTONE, which would be available in late 1957, could carry a warhead of 6900 pounds and, by sacrificing some range, a warhead of 7800 pounds. Since all these applications were some time in the future, the Committee decided that emphasis would continue on the bomb program.[35]

(b)(1), (b)(3)

At the May 21, 1954 meeting of the TX-Theta Committee, Sandia reported difficulties in designing a true contact fuze. This fuze had to be sensitive enough to operate properly in both retarded and free-fall drops, and at the same time be insensitive to rain and hail, as well as shock caused by detonation of antiaircraft shells. The TX-15 secondary was in the front end of the weapon, and thus would be physically damaged soon after weapon contact with the terrain.[36] The Committee concluded that a satisfactory contact fuze could not be developed for the TX-15 within the time scales of the weapon, and that the proximity fuze should be used.

Report SC3390(Tr), Proposed Ordnance Characteristics for the TX-15 Weapon, was discussed at the June 30, 1954 meeting of the Special Weapons Development Board.

(b)(3)

The TX-15 was 34-1/2 inches in diameter, 130 inches long, and weighed 7500 pounds.

(b)(1), (b)(3)

Pullout switches closed at release of the bomb from the aircraft, and battery power started operation of the inverters. After the safe-separation interval timer completed its cycle, the X-unit could be charged by closure of the arming baro. When the detonation altitude was reached, the firing baro closed, connecting the output of the X-unit to the detonators.

(b)(3)

The weapon would be stored in a completely assembled condition, less power supply and primary capsule. The only disassembly permitted would be for inspection of firing set, detonators and interconnecting cables, and a surveillance break was provided for this purpose just forward of the primary. Since the program was urgent, and since any prospective missile carriers were still far in the future, the TX-15 was restricted to bomb application.[38] Field Command suggested that the weapon case be sealed, to provide protection against its environment, and Sandia provided internal seals for all case joints..

(b)(3)

The Mk 15 Mod 0 Bomb was design-released in October 1954. Four major changes had been made since the Proposed Ordnance Characteristics had been issued. One was the sealing of the weapon case. Plastic liners between the inside of the case and the exterior of the secondary were replaced by liners made of rubber. This change eliminated machining and resulted in a more closely controlled product.

(b)(3)

The bomb was stockpiled April 1955.

A proximity fuze was incorporated in the production weapons.

(b)(1), (b)(3)

(b)(1), (b)(3)

Radar antennas were installed in the bomb fins, where they gave good coverage, not only straight ahead of the bomb but to the side. This caused detonation if the Mk 15 dropped close to the side of a building.[40]

Subsequent component testing for temperature, humidity, pressure, vibration, shock, dust and salt spray showed that all components, with some few exceptions, could satisfactorily withstand these environments. In the few exceptions, it was decided that the item would never experience the condition prescribed. Environmental tests were performed on six complete weapons, and included cycles of artic, desert and tropical conditions. These tests were successfully passed, as were various dynamic tests. Flyaround tests were conducted in a B-47, to detect any adverse vibrational frequency ranges, and the weapon was catapulted in an A3J. Drop-tower tests simulated the maximum loads on the bomb caused by carriage in various aircraft. The weapon was dropped from a height of 20 inches onto a concrete platform, propelled down a ramp and into a wall, and subjected to standard railway humping tests. The full-scale drop program included 11 ballistic and 22 fuzing and firing drops. To create extreme release conditions, two drops were accelerated by jato boosters.

Consideration again turned to the problem of developing a missile warhead, and a thorough discussion was held in a joint meeting of the TX-Theta and TX-N Committees on January 6, 1955. The design was still too heavy, but it was felt that perhaps 800 pounds might be shaved off the weight by reducing the thickness of the aluminum case.[41]

Some attention was given to carriage of the XW-15 on the F-101 aircraft. The project would have required a streamlined shape for external carriage known as Shape 96.[42] However, the program was later canceled.

Meetings had meanwhile been held at Redstone Arsenal to discuss installation of a warhead in the REDSTONE missile.

(b)(3)

(b)(1), (b)(3)

The missiles were the Army's REDSTONE and the Air Force's SNARK and NAVAHO.[45, 46]

Development requirements for the installation of a Mk 15 Warhead in the Pod of the B-58 or Hustler airplane were established and, during 1955, the program was alternately canceled and revived.[47] By the end of the year, however, it had been decided to delete all applications of the Mk 15 Warhead, and to use the Mk 39 weapon.[48]

Meanwhile, work had been proceeding on the development of true contact fuzing for the Mk 15 Bomb, with several possible methods being studied. The use of probes, both fixed and extendible, was discarded, as it was found that too much of the weapon area was left insensitive to impact. A design using a double shell, having laminated layers of insulator and contact material which would crush on contact, was found to be overly sensitive to antiaircraft fire.

(b)(1), (b)(3)

The most practical method appeared to be the use of barium titanate crystals which, under pressure, produced a pulse of energy. Development of this device resulted in good reliability and high performance. Thermal-cell batteries would replace the nickel-cadmium units, and required no preparation or maintenance.[49]

A proposal was made that this new fuze be applied to Mk 15 weapons that would have only a bomb capability (at that time, the warhead application was still being considered).[50]

(b)(1), (b)(3)

Requirements for these programs had been generated by a letter from the Secretary for Defense dated May 3, 1955.

The Military Liaison Committee had meanwhile become concerned that a lightweight bomb would require quite different handling equipment than that provided for the Mk 15 Mod 0, and suggested that new nomenclature be assigned.[47] Thus, on December 2, 1955, the Division of Military Application redesignated the Mk 15 modification program of weight reduction, contact fuzing, and thermal battery, s the TX-39. The Mk 15 modification of [54] contact fuzing and thermal battery alone would be the Mk 15 Mod 1 Bomb. This latter program was later canceled when it was found that the production complex could not deliver enough critical components to support all the using programs.

(b)(1), (b)(3)

A trajectory arm switch was added to the fuzing system to prevent power from reaching the X-unit until the bomb had experienced a normal release.[55] These changes were incorporated in the Mk 15 Mod 2 Bomb which entered stockpile in March 1957.

TX-29

(b)(1), (b)(3)

Early in 1954, a feasibility study of the warhead was authorized for use with the NAVAHO, a supersonic, surface-to-surface, pilotless bomber (as the missiles were called in those days), capable of striking targets at ranges up to 3500 nautical miles.[56]

(b)(1), (b)(3)

Subsequently, the Division of Military Application notified the Military Liaison Committee March 16, 1955, that it appeared better to proceed with modifications to the Mk 15 program, which would provide a lighter case and a contact fuze, than to continue with work on the TX-29.[58]

It was pointed out that a completely new design, such as the TX-29, might provide a slightly increased yield over the Mk 15 design.

(b)(1), (b)(3)

The program was subsequently canceled by the Division of Military Application August 25, 1955.[52]

TX-16

(b)(3)

This was analogous to holding a lighted match under a large block of wood for a few seconds--not long enough for the wood to catch fire.

(b)(3)

However, the lack of a high-capacity, high-speed computer to perform the necessary extensive calculations hampered this approach.

(b)(1), (b)(3)

(b)(3)

Mk 17/24

(b)(1), (b)(3)

It was noted that the yield of such a device was thoroughly uncertain, but that it was quite unlikely to be of weapons interest.[2]

Subsequently, more confidence was developed in this design, and it was assigned a nomenclature of TX-17.[67] Sandia would be responsible for the design and production of the afterbody, fuze power supply, parachute and pertinent test and handling equipment. The TX-14 baro fuze would be used in the early weapons but be replaced by a proximity fuze as soon as possible.[68]

(b)(1), (b)(3)

(b)(1), (b)(3)

The Mk 17/24 Mod 1 was design-released December 1954 and appeared in stockpile March 1955. By September 1955, all the Mod 0's in stockpile had been converted to the Mod 1 configuration.[22]

In the meantime, work had been proceeding on the design of a proximity fuze, but many difficulties had been encountered.[81] Additionally, the Military--and especially the Strategic Air Command--had developed increasing interest in true contact bursts, to be used for cratering enemy air fields. Sandia thus decided to design a true contact-burst fuze, and to apply this initially to the Mk 17/24 weapons. /

(b)(3)

/The initial approach was to design a contact fuze that would operate against hard, flat targets, with the bomb striking in a nearly vertical position. Tests would then be made to discover how far the fuze could be extended for more severe impact conditions.[82]

It was relatively simple to design contact fuzes for fission weapons, since these devices were covered with a light ballistic fairing that was able to sense the shock of impact and signal detonation before any real physical damage was done to the weapon. However, in thermonuclear devices, the heavy case would have to sense the impending shock and detonate just before actual impact took place.

Discussions with Los Alamos led to the conclusion that the secondary reaction would occur if the primary reaction was completed, and it was decided to use a barium titanate crystal contact fuzing system developed for fission bombs.[83] Sandia performed some sled tests in Area III, from which a design was evolved using two networks each containing two impact crystals, mounted on the nose of the bomb. A fast-firing gap-type X-unit was concurrently developed.

Further work on parachutes was necessary, in order to produce a design which would permit releases from B-52 bombers and result in a down-time of 75 seconds. Sandia placed an order on Wright Air Development Center for both standard and heavy-duty parachutes with diameters of 40 feet. The first phase of this testing program was completed January 19, 1955, after eight drops had been made with standard chutes. Test results showed that opening shocks were lower than expected. However, the requirement for carriage in the B-52 was canceled April 24, 1956, due to release troubles in which the suspension sling failed to retract properly. Subsequently, the Strategic Air Command decided to use a 64-foot-diameter chute and to place an operational restriction of 365 knots airspeed and 20,000-foot altitude on the weapon at release.

The Mk 17/24 Mod 2 Bomb was design-released June 1, 1955. The weapon contained a Mk 17 Mod 0 Fuze, with both contact- and air-burst capabilities. The bomb was 61.4 inches in diameter, 298 inches long, and weighed 42,000 pounds.

(b)(1), (b)(3)

The fuzing operation could be selected by a control in the bomber before weapon release.

(b)(3)

The weapon could be stored for 18 months under stockpile storage

(b)(1), (b)(3)

Teapot -- A less-than-full-scale test series held at the Nevada Test Site. Series of 14 tests, starting February 18 and ending May 15, 1955.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

Ton (Yield) -- A means of measuring the yield of an atomic bomb by comparing its output with the effect of an explosion of TNT. A 1-ton yield is equivalent to the detonation effect of 2000 pounds of high explosive.

Tritium -- The hydrogen isotope of mass number 3.

Two-Stage -- Combination of fission and fusion action in a weapon.

TX-N Committee -- A joint committee of Los Alamos Scientific Laboratory and Sandia members, established to guide the development of implosion-type weapons.

TX-Theta Committee -- A committee established to guide the development of thermonuclear weapons.

University of California Radiation Laboratory -- A laboratory established under the guidance of the University of California to work on thermonuclear designs, and located at Livermore, California. The laboratory was founded largely as the result of the interest of Dr. Edward Teller in pursuing thermonuclear work.

Upshot-Knothole -- Tests of atomic devices, held at the Nevada Test Site. Series of 11 shots, starting March 17 and ending June 4, 1953.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent of uranium-238; the rest is uranium-235.

Wooden Bomb -- A weapon designed to have an infinite shelf life and to require no special storage or surveillance. "As trouble-free as a block of pine."

X-Unit -- ~~A high-voltage transformer.~~ A device used to furnish high voltage to the weapon detonators.

Yaw -- Motion of the bomb as it falls through the air, such that it alternately veers left and right.

Yield -- ~~A means of~~ measuring the effect of a nuclear detonation ~~by~~ comparing it to ~~with~~ the effect of an explosion of TNT. By definition one kiloton is 10^{12} calories.

Yucca Lake Range -- A test range located at Yucca Lake, Nevada.

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September 1967

RS 3434/11

(b)(3)

Mks 21, 22, 26 and 36

SC-M-67-662

Weapon Systems

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Information Research Division, 3434

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(b)(3)

MK 21/~~26~~ 36

(b)(1), (b)(3)

The Mk 17 weighed over 21 tons and consequently was difficult to transport and handle.

(b)(1), (b)(3)

It had a diameter of 60 inches and a length of 145 inches (both dimensions controlled by the size of existing aircraft bomb bays), and a weight of 20,000 pounds.[1]

(b)(1), (b)(3)

The committee proposed that if the test was successful, the device be weaponized, and assigned nomenclature of TX-21 to the program.[2,3]

(b)(1), (b)(3)

Sandia meanwhile had started scale studies of the TX-21 shape and, by early March 1954, had determined that it would require at least one spoiler band on the nose and another on the afterbody to produce adequate free-fall stability. It was thought that a flat area on the nose might eliminate the need for a nose band, and appropriate tests were scheduled. It was estimated that external dimensions could be definitely fixed by mid-1954; fuzing, firing and ballistic drop tests held in early 1955; design release effected in mid-1955; and early Mark production by January 1956.[5]

The weight of the bomb was discussed in the March 26, 1954 meeting of the TX-Theta Committee. (b)(3) This would allow the weapon to be delivered by the B-58 or Hustler bomber, then being designed. Los Alamos stated that any weight-reduction study would delay the overall program, and noted that bombers could refuel in the air after takeoff. There would thus be little difference in bomber range due to weapon weight.

After discussion, the Committee decided that an attempt would be made to trim the weight to 15,000 pounds. Sandia would test wind-tunnel models representing diameters between 48 and 54.5 inches, and would study the component space problems created by such diameters. It was requested that this investigation delay the program not more than one month.[6]

The military characteristics for a two-stage weapon in the 23,000-pound maximum weight class were released April 15, 1954.

(b)(1), (b)(3) It was stated that more than one ballistic shape might be required for these various applications, but that the number of such shapes should be held to a minimum.

(b)(1), (b)(3)

The bomb was to be capable of being released either free fall or retarded as inflight-selectable options. Remotely controlled automatic nuclear arming and safing would be possible at any time prior to release of the bomb from the aircraft. A safe-separation time should be provided, and the weapon was to be able to provide either air burst or surface burst, with the latter feature acting as cleanup in the event of malfunction of the air-burst option. The burst height would be settable prior to flight. Any power source provided would have a storage life of from 2 to 5 years, require no preflight preparation beyond installation in the bomb, and no activation other than weapon release. The battery life after installation was to be at least equal to the time interval between normally scheduled inspections of the assembled bomb.[7]

It was felt that the TX-21 might have a diameter of 47.5 inches, a length of 147 inches in the parachute-retarded version, and would weigh between 15,000 and 16,000 pounds. The bomb would be compatible with the aircraft specified in the military characteristics.

(b)(1), (b)(3)

The parachute could be reefed for shorter times of fall. The air-burst fuze would be timer-armed and baro-fired.[8]

The results of wind-tunnel experiments now became available and were discussed in the April 23, 1954 meeting of the TX-Theta Committee. The tests had been made at a speed of Mach 0.93 on models with scale diameters of 48, 51, 52 and 54.44 inches. A quarter-caliber ogive nose had produced poor results. A hemispherical nose with a 0.4-caliber flat had resulted in fair dynamic stability with no spoiler bands, and good stability with one band located between Stations 77 and 103. Good pressure-sensing results had been secured, and more testing was scheduled.

Sandia noted that the ready-weapon philosophy adopted for the TX-15 would also be used for the TX-21. A sealed storage container would be provided and the

weapon would be packaged in this container with fins attached and fuze installed. Most of the bomb would thus be assembled, and a minimum of strike assembly checks would be required during a ready-weapon life of 90 days.[9]

By the April 28, 1954 meeting of the Special Weapons Development Board, the diameter of the TX-21 had been increased to 52 inches, as it was desired to provide the largest weapon that could be carried by the B-47, the weapon's primary carrier.

(b)(3)

It was found that the P6M aircraft might subject the bomb to a vertical acceleration of 7.5 g's, and this might degrade the weapon's reliability. Additionally, the weapon fins would have to be relocated to allow the bomb to fit the rotating bomb-bay door of the P6M.[10] It was decided to concentrate on B-47 compatibility, and to consider application to other bombers at a later date.[11]

Additional discussion was held in the May 21, 1954 meeting of the TX-Theta Committee. Los Alamos was concerned that the weapon's efficiency might be sacrificed by an effort to reduce weight, and it was felt unwise to release any light design for stockpiling without proof tests

(b)(1), (b)(3)

Sandia noted that this change would require a new series of wind-tunnel tests. The final decision was to allow a weight increase, as the B-47 would have to refuel after takeoff with a 15,000 pound bomb, and the aircraft range would not be greatly affected by the heavier bomb weight.[12]

Scale model tests were conducted at the Cornell Wind Tunnel May 26-27, 1954, and discussed in the June 4, 1954 meeting of the TX-Theta Committee. Ten nose shapes had been tested, and the best results were obtained from a hemispherical nose with a half-caliber flat.

(b)(1), (b)(3)

The two weapons would have a near-contact burst as the primary option, achieved by a network of proximity fuzes, and these units would provide backup for the secondary air-burst option. The fuzing and firing systems in both options would be armed by a barometric switch. A true contact fuze for thermonuclear applications was being developed, but this design would require extensive testing.

Work was progressing on improved types of power sources, which would meet military requirements of minimum preparation time and long storage life; but nickel-cadmium batteries would be used in the early stockpiled weapons. A retarded trajectory was desired, due to the large yield of the weapon, and would be provided by a 24-foot-diameter parachute, reefed to provide a down-time of 75 seconds, as compared to an unreefed time-of-fall of 108 seconds. Use of this parachute would be controlled by equipment installed in the aircraft.

It was noted that the diameter of the bomb over the spoiler bands was 58.47 inches, the overall length was 148.37 inches, and the weight was 17,600 pounds.[20] The outer case was an aluminum-alloy shell which formed the main structural member of the bomb.

(b)(1), (b)(3)

The afterbody was a cylindrical extension of the warhead case, having the same diameter and being attached to it by an external bolting flange which also served as an aerodynamic spoiler band. Access doors were provided for battery installation, safety switch, and interconnecting box. All fuzing and firing components, with the exception of X-unit and pullout switch, were mounted on a plate readily accessible through the tail of the bomb after the parachute container was removed.

The bomb had four fins, with a 6- to 14-degree double-wedge shape, a 39-1/2-inch chord length, and an 80.9-inch span. The forward half of each fin was of sheet metal and the remainder of polyester-glass laminate. A proximity-fuze antenna was installed in the plastic portion of each fin.

Deployment of the 24-foot-diameter parachute could be selected at any time prior to weapon release. Fuzing and firing system components were the same as the TX-15 Bomb, with the exception of X-unit and cabling. A remote-setting baroswitch provided a detonation signal for air bursts, and a network of four proximity fuzes provided the signal for near-contact bursts, as well as cleanup for air-burst failures. Safe separation was provided by a baroswitch that was set prior to takeoff of the strike bomber.[21]

The Division of Military Application notified the Military Liaison Committee October 25, 1954, that the TX-21 would be design-released in March 1955, with stockpile entry in August 1955. To meet this schedule, it had been necessary to assign the highest priority to the development.

(b)(1), (b)(3)

Report SC3608(TR), Design and Description Report at Design Release of the Mk 21/26 Mod 0 Bomb, was reviewed in the June 1, 1955 meeting of the Special Weapons Development Board. The bomb was 58.48 inches in diameter over the spoiler bands, and 149.6 inches long. (b)(1), (b)(3)

Either free-fall or parachute-retarded deliveries were possible. A 16-foot parachute furnished a 75-second time-of-fall.

The drop-test program was still under way, with nine ballistic and three fuzing and firing drops completed. Ballistic performance was satisfactory, but some parachute oscillations had been noted, and this problem was being solved as the test program progressed.

(b)(1), (b)(3)

This required an increased aircraft escape time of 100 seconds, and Wright Air Development Center was requested to develop a 24-foot-diameter parachute. It was felt that a two-stage deployment system would have to be used to mitigate the opening shock of the larger canopy.[33]

Report SC3694(TR), Engineering Evaluation of the Mk 21 Mod 0 Weapon, was presented to the December 14, 1955 meeting of the Special Weapons Development Board. Environmental resistance had been determined by component testing to performance standards, as well as overall weapon testing in arctic, tropic and desert environments. Models had been subjected to thermal tests; tests simulating loads involved in flights of B-47 and P6M aircraft; railroad humping tests; and rain, sand, dust, salt spray and sunshine tests. A total of 42 units had been drop-tested, including ballistic free-fall units, ballistic parachute units with proximity fuzes, ballistic parachute units with contact fuzes, and fuzing and firing units.

(b)(1), (b)(3)

Based on the testing program, it was believed that the weapon design imposed no operational limitations within the stockpile-to-target sequence and that the bomb met the military characteristics with the exception of the following: (1) The weapon weighed 17,500 pounds instead of the desired 15,000 pounds; (2) nickel-cadmium, rather than thermal, batteries were used; (3)

(b)(1), (b)(3)

and (4) the parachute design did not meet the military characteristics. Work was continuing in an effort to improve the last two points.

(b)(1), (b)(3)

Parachutes had to be inspected and repacked every 3 months, and drop aircraft were not to exceed a release velocity of 400 knots. On September 24, 1956, this release velocity was increased to 500 knots; and on July 12, 1957, a general release, with no limitations, was issued.[35, 36]

The sequence of events in the fuzing and firing sequence was as follows: ~~For the~~ For the air-burst option, either free-fall or parachute-retarded option could be selected. The arm baroswitch was set at the desired arming altitude prior to takeoff of the bomber. During flight to the target area, power was applied to the battery heaters, the firing baroswitch was set to the selected altitude, the nuclear capsule was remotely inserted, and the safing switch was armed.

When the bomb was released, withdrawal of the arming wires closed the pullout switch and supplied power to the fuze. The inverters started operation and,

after the safe-separation interval (determined by the setting of the arm baro-switch), the X-unit started to charge and the proximity fuzes were armed. A 3-second delay was provided by a timing device to prevent firing before the X-unit attained its normal charge.

As the bomb reached the desired burst altitude, the firing baroswitch closed, actuating the firing switch in the X-unit, discharging the capacitor bank into the detonator bridge wires, and initiating the explosive and nuclear sequence. If the system malfunctioned, the proximity fuze detonated the bomb. The parachute was deployed after release from the aircraft, if the retarded option had been selected. If a near-surface burst was selected, the barometric fuze was set at -3000 feet and the proximity fuze detonated the weapon.

(b)(1), (b)(3)

The Mk 21 Mod 0 first appeared in stockpile December 1955, and final deliveries were made in July 1956.

(b)(1), (b)(3)

The TX-26 was never authorized for production.[38]

Meanwhile, work had been proceeding on the design of a true contact fuze.[39] Report SC3606(TR), Proposed Electrical Characteristics for the Fuzing and Warhead Systems for the TX-15-X1 and the TX-21/26-X1 Weapons, was presented to the April 27, 1955 meeting of the Special Weapons Development Board.

(b)(1), (b)(3)

(b)(1), (b)(3)

Four methods of producing contact bursts had been considered. The first was the use of nose probes, both fixed and extendible. Study showed that this system was not ideal, since much of the weapon was left insensitive to impact. A second possibility was the use of an insulated double shell, which would crush on contact and produce a firing signal. This was a one-shot type of device, and was very sensitive to antiaircraft fire. A third method was the use of low-burst (1- to 25-foot) proximity fuzes, but these required further development. The fourth was use of barium titanate crystals, and appeared the most promising.

(b)(1), (b)(3)

The contact fuze was discussed in the June 1, 1955 meeting of the Special Weapons Development Board when Report SC3607(TR), Proposed Ordnance Characteristics for the TX-21/26-X1 Weapon, was presented. The report noted that four contact crystals would be mounted on the nose of the bomb and a fast-firing X-unit installed. The modified design would be released in February 1956 and Mark units produced by late 1956.[32]

During the development drop program of the TX-21-X1, data were obtained that caused concern over the operation of the contact crystal fuzing network.

(b)(1), (b)(3)

A joint letter from Sandia and Los Alamos was forwarded to the Santa Fe Operations Office June 19, 1956. This noted that the possibility of providing a boosted, externally initiated primary had been studied.

(b)(1), (b)(3)

Field Command notified Albuquerque Operations November 1, 1956, that the Mk 21 handling equipment caused spalling of concrete floors in storage igloos. This was due to the hard casters of the weapon bolster, and development of a suitable wishbone trailer was requested.[46] Sandia subsequently designed and produced a prototype device incorporating rubber tires.[47]

All Mk 21 Bombs were withdrawn from stockpile in the period June through November 1957, and were converted into Mk 36Y1 Mod 1's.[38]

(b)(1), (b)(3)

TX-22 Cross-Section

Timetable of TX-22 Events

9/18/53 (b)(1), (b)(3)

10/29/53 Santa Fe Operations Office authorizes Sandia to assist in the above design.

2/2/54

(b)(1), (b)(3)

4/30/54

TX-22

(b)(1), (b)(3)

Sandia was requested to develop preliminary ballistic configurations, as well as requisite parachute ~~and~~ and fuzing and firing components.[48]

(b)(1), (b)(3)

The Santa Fe Operations Office requested Sandia, October 29, 1953, to assist the Radiation Laboratory in work on the aerodynamic case. Sandia would also design the fuzing and firing system, and conduct flight tests for both ballistics and systems prove-out.[49]

A review of a prospective drop-test program was held November 19, 1953. The devices would be released from a B-36 bomber flying at an altitude of 40,000 feet.

(b)(1), (b)(3)

The question of parachute retardation was raised, and was subsequently referred to the Air Force Special Weapons Center.

(b)(1), (b)(3)

(b)(1), (b)(3)

However, the Santa Fe Operations Office, in a letter dated March 17, 1954, stated that any ballistic or fuzing and firing work on this design would be of minimal value, since the weaponized version would probably differ greatly from the test device. It was suggested that plans be made to hold the test on a barge, thus obviating the need for case design.[57]

(b)(1), (b)(3)

Timetable of Mk 36 Events

11/22/55	(b)(1), (b)(3)
1/3/56	TX-36-X1 design released.
4/56	Mk 36 Mod 0 enters stockpile.
5/56	Mk 21/36 Mod 1 Bomb design released.
7/13/56	TX-36-X2 program authorized for development.
9/24/56	(b)(1), (b)(3)
10/24/56	Proposed ordnance characteristics of TX-36-X2 Bomb reviewed by Special Weapons Development Board.
10/56	Mk 21/36 Mod 1 Bomb enters stockpile.
11/15/56	(b)(1), (b)(3)
4/12/57	TX-36-X2 program suspended.
4/22/57	(b)(1), (b)(3)
7/11/57	Resumption of work on TX-36-X2 authorized.
7/57	(b)(1), (b)(3)
4/23/58	TX-36-X2 design released.
1/9/59	Albuquerque Operations Office cancels Mk 36 programs.

Mk 36

(b)(1), (b)(3)

The TX-21-X1 program was subsequently canceled, but the TX-36-X1 was design-released January 3, 1956, and became, in production, the Mk 36 Mod 0.[63, 64] The weapon entered stockpile in April 1956 with a proximity fuze and internal initiator.[38]

Meanwhile, other improvements in the Mk 21 design had been suggested, principally in the fuzing and firing system. This work had begun in early 1955 in connection with the Mk 15 and Mk 39 programs, and the proposed design would provide options of either air burst or true contact firing. The weapon would be armed and fired by barometric switches, and the contact crystals would act either as primary fuze or as backup to the air-burst system. Thermal batteries would replace the nickel-cadmium units and would supply both low-voltage power for the fuzing system and high-voltage power for charging the X-unit.

Report SC3826(TR), Design and Description Report at Design Release of the Mk 21/36 Mod 1 Bomb, was released May 1956. This noted that the yield, weight, and

physical configuration of the Mod 1 was essentially identical with the Mod 0, with the exception of the fuzing and firing system. The Mod 1 would be employed in a high-altitude level release, using either a free-fall or retarded trajectory.

(b)(1), (b)(3)

Baroswitch settings were made on the ground prior to aircraft takeoff by a single dial setting. This setting was computed by comparing the intended height of burst with the target elevation above sea level and including a 300-foot offset correction. Prior to bomb release from the strike aircraft, the selector switch was placed at either air- or ground-burst position, the nuclear capsule inserted, the safing switch placed in the armed position, and the option switch placed at either the open or closed position, depending on whether ground or air burst had been selected.

The release of the bomb from the aircraft closed a pullout switch in the high-voltage-battery firing circuits, and operated magneto generators which furnished electrical pulses to ignite the low-voltage batteries. Power from these batteries was applied to the open contacts of the arm baroswitch. When the arm baroswitch closed, at the appropriate point in the weapon trajectory, low-voltage power was applied through the closed pullout switch and safing switch to the activating circuits of the high-voltage batteries, placing these latter devices in operating condition. The 2500 volts provided by these batteries charged the X-unit and supplied plate voltage to the trigger circuit.

If air-burst option had been selected, closure of the firing baroswitch applied a signal from the low-voltage batteries to the trigger circuit, thus detonating the bomb. If ground-burst option had been selected, the option switch held the firing circuit open, allowing the weapon to fall to the ground, where the contact fuze supplied the detonation signal.[65]

The Mk 21 Mod 1 Bomb was never produced, but the Mk 36 Mod 1 design entered stockpile in October 1956.

(b)(1), (b)(3)

(b)(1), (b)(3)

/The TX-36-X2 would be design-released in June 1957 with early production scheduled for July 1958 and operational availability in the fall of 1958.[69]

(b)(1), (b)(3)

(b)(1), (b)(3) Albuquerque Operations Office replied February 13, 1957, noting that Sandia and Los Alamos would issue a joint reply after TX Committee meeting of February 21, 1957.

(b)(3)

The Division of Military Application replied that these rates could not be currently established, as no production directive had been released.

(b)(1), (b)(3)

Subsequently, April 12, 1957, all activity on the TX-36-X2 program was suspended by the Albuquerque Operations Office, based on an expectation that the program would be canceled.[76]

(b)(1), (b)(3)

Sandia was requested to prepare a product definition as soon as possible.[77]

Sandia wrote to the Albuquerque Operations Office May 3, 1957, proposing that nomenclature for the Mk 36 Mod 1 Bomb include the designations Y1 and Y2.[78]

(b)(1), (b)(3)

The foregoing was forwarded to the Division of Military Application February 17, 1958, with a production recommendation. It was noted that the design would provide safety features that had been suggested by the Air Force Special Weapons Center and that the modification could be completed by September 1959.[85]

The Division of Military Application sent a teletype to the Albuquerque Operations Office April 10, 1958, authorizing modification of some Mk 36 Mod 1/Y1 and Y2 Bombs to the TX 36-X3 configuration.[86] This program had been approved by the Military Liaison Committee, which agreed that weapon safety would be thereby materially increased.[87]

Report SC4146(TR), Description and Status at Complete Design Release of the TX-36Y1-X2 Bomb, was presented to the April 23, 1958, meeting of the Special Weapons Development Board and subsequently released in May 1958.

(b)(1), (b)(3)

The design had been authorized for development July 13, 1956, suspended April 12, 1957, and work resumed July 11, 1957.

(b)(1), (b)(3)

A new fuzing and firing system was provided, but the contact fuze was retained.

(b)(3)

(b)(3)

Report SC4222(TR), Final Evaluation of the Mk 36Y2 Mod 1 Bomb, was presented to the December 17, 1958, meeting of the Special Weapons Development Board.

(b)(1), (b)(3)

(b)(1), (b)(3)

Dynamic drop tests to ultimate loads, railroad humping tests, extreme temperature tests, and a simulated 6-month tropic storage test had been conducted, and these demonstrated the ability of the weapon to withstand these environments.[89]

At the above Board meeting, Report SC4188(TR), Final Evaluation of the Mk 36Y1 Mod 2 Bomb, was also presented.

(b)(1), (b)(3)

About half the existing stockpile of Mk 36Y1 Mod 1 Bombs would be converted to this new design, which had been called in development the TX-36-X2.

(b)(3)

The program included environmental, drop and neutron-generator compatibility tests, and demonstrated that the weapon was more than adequate to withstand the stockpile-to-target sequence. Both land and water targets had been included in the drop-test program, with release altitudes between 20,000 and 50,000 feet.[89]

On January 9, 1959, Albuquerque Operations Office canceled the Mk 36 program. The Mk 36 Mod 1 Bombs scheduled for updating would remain in current status until retirement in mid-1959.[90] This retirement program was later deferred to mid-1961.

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Glossary of Terms

Air Force Special Weapons Center -- That element of the Air Force Systems Command having to do with compatibility testing of nuclear devices with aircraft. Located at Kirtland Air Force Base, Albuquerque, New Mexico.

Albuquerque Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with the operations of Sandia Corporation.

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions related to atomic weapons.

Arming -- The act of arming a weapon; that is, preparing it for firing.

(b)(1), (b)(3)

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

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Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

Tritium -- The hydrogen isotope of mass number 3.

Two-Stage -- Combination of fission and fusion action in a weapon.

TX Committee -- A joint committee of Los Alamos and Sandia members, established to guide the development of implosion-type weapons.

TX-Theta Committee -- A committee established to guide the development of thermonuclear weapons.

University of California Radiation Laboratory -- A laboratory established under the guidance of the University of California to work on thermonuclear designs, and located at Livermore, California.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

X-Unit -- ~~A high-voltage transformer~~. A device used to provide high voltage to the weapon detonator.

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UNCLASSIFIED

September 1967

RS 3434/11

(b)(3)

Mks 21, 22, 26 and 36

SC-M-67-662

Weapon Systems

SC-M-67-662
DC-3434/ 11
09/67

Information Research Division, 3434

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Systematic Declassification Review
MAIN CLASSIFICATION
R. T. Duff 2/12/97
Reviewer Date

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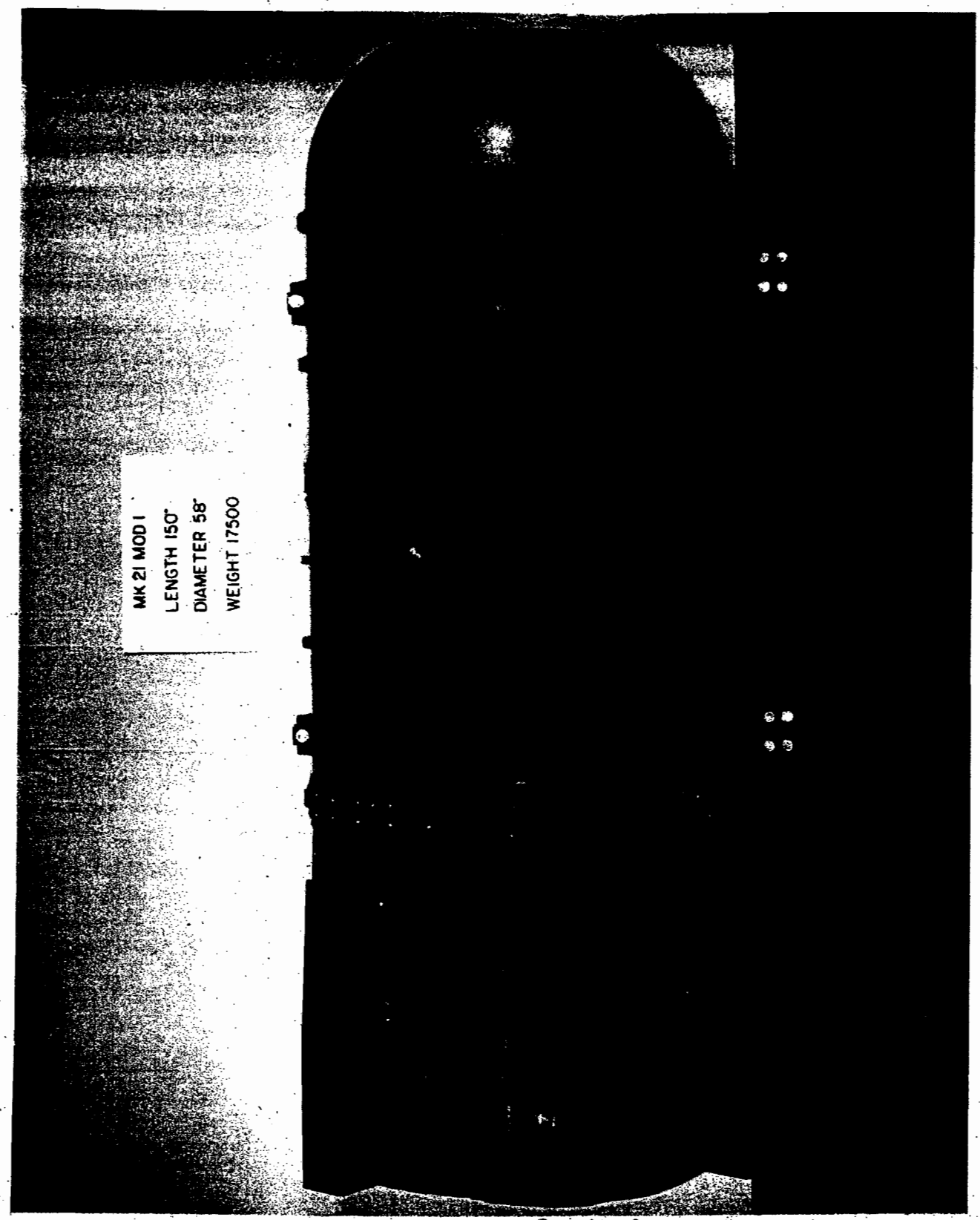
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Classification Analyst, Org 4225
Date: 12/12/2007
Derived From: TCG-NAS-2, 03/97, DOE OC

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Mk 21 Exterior View

Timetable of Mk 21/26 Events

1/15/54	TX-Theta Committee meets. (b)(1), (b)(3) TX-21 nomenclature assigned.
	(b)(1), (b)(3)
3/26/54	Weight reduction of TX-21 proposed.
4/15/54	Military characteristics released. (b)(1), (b)(3)
6/4/54	TX-Theta Committee proposes expedited schedule.
6/7/54	Santa Fe Operations Office issues go-ahead on TX-21 design.
7/1/54	Military Liaison Committee approves expedited schedule for TX-21.
7/23/54	Results of wind-tunnel tests reported.
9/1/54	Contact fuze proposed. (b)(1), (b)(3)
9/29/54	Proposed ordnance characteristics of TX-21 reviewed.
12/15/54	Air Force Special Weapons Center requests weight reduction.
1/6/55	(b)(1), (b)(3)
5/9/55	Aerodynamics report on TX-21 ballistic shape issued.
6/1/55	Design of Mk 21/26 reviewed by Special Weapons Development Board.
7/15/55	(b)(1), (b)(3) Parachute provided for retarded deliveries.
12/55	Mk 21 Mod 0 Bombs stockpiled.
6/27/56	Mk 21 Mod 1 with contact fuze design-released. TX-26 design subsequently deleted from program.
6/57	Stockpiled Mk 21 Bombs converted to Mk 36Y1 Mod 1.
11/57	Conversion program completed.

Sandia meanwhile had started scale studies of the TX-21 shape and, by early March 1954, had determined that it would require at least one spoiler band on the nose and another on the afterbody to produce adequate free-fall stability. It was thought that a flat area on the nose might eliminate the need for a nose band, and appropriate tests were scheduled. It was estimated that external dimensions could be definitely fixed by mid-1954; fuzing, firing and ballistic drop tests held in early 1955; design release effected in mid-1955; and early Mark production by January 1956.[5]

The weight of the bomb was discussed in the March 26, 1954 meeting of the TX-Theta Committee. (b)(3) This would allow the weapon to be delivered by the B-58 or Hustler bomber, then being designed. Los Alamos stated that any weight-reduction study would delay the overall program, and noted that bombers could refuel in the air after takeoff. There would thus be little difference in bomber range due to weapon weight.

After discussion, the Committee decided that an attempt would be made to trim the weight to 15,000 pounds. Sandia would test wind-tunnel models representing diameters between 48 and 54.5 inches, and would study the component space problems created by such diameters. It was requested that this investigation delay the program not more than one month.[6]

The military characteristics for a two-stage weapon in the 23,000-pound maximum weight class were released April 15, 1954.

(b)(1), (b)(3)

It was stated that more than one ballistic shape might be required for these various applications, but that the number of such shapes should be held to a minimum.

(b)(1), (b)(3)

The two weapons would have a near-contact burst as the primary option, achieved by a network of proximity fuzes, and these units would provide backup for the secondary air-burst option. The fuzing and firing systems in both options would be armed by a barometric switch. A true contact fuze for thermonuclear applications was being developed, but this design would require extensive testing.

Work was progressing on improved types of power sources, which would meet military requirements of minimum preparation time and long storage life; but nickel-cadmium batteries would be used in the early stockpiled weapons. A retarded trajectory was desired, due to the large yield of the weapon, and would be provided by a 24-foot-diameter parachute, reefed to provide a down-time of 75 seconds, as compared to an unreefed time-of-fall of 108 seconds. Use of this parachute would be controlled by equipment installed in the aircraft.

It was noted that the diameter of the bomb over the spoiler bands was 58.47 inches, the overall length was 148.37 inches, and the weight was 17,600 pounds.[20] The outer case was an aluminum-alloy shell which formed the main structural member of the bomb.

(b)(1), (b)(3)

The afterbody was a cylindrical extension of the warhead case, having the same diameter and being attached to it by an external bolting flange which also served as an aerodynamic spoiler band. Access doors were provided for battery installation, safety switch, and interconnecting box. All fuzing and firing components, with the exception of X-unit and pullout switch, were mounted on a plate readily accessible through the tail of the bomb after the parachute container was removed.

The bomb had four fins, with a 6- to 14-degree double-wedge shape, a 39-1/2-inch chord length, and an 80.9-inch span. The forward half of each fin was of sheet metal and the remainder of polyester-glass laminate. A proximity-fuze antenna was installed in the plastic portion of each fin.

Deployment of the 24-foot-diameter parachute could be selected at any time prior to weapon release. Fuzing and firing system components were the same as the TX-15 Bomb, with the exception of X-unit and cabling. A remote-setting baroswitch provided a detonation signal for air bursts, and a network of four proximity fuzes provided the signal for near-contact bursts, as well as cleanup for air-burst failures. Safe separation was provided by a baroswitch that was set prior to takeoff of the strike bomber.[21]

The Division of Military Application notified the Military Liaison Committee October 25, 1954, that the TX-21 would be design-released in March 1955, with stockpile entry in August 1955. To meet this schedule, it had been necessary to assign the highest priority to the development.

(b)(1), (b)(3)

(b)(1), (b)(3)

It was hoped that a contact fuze could be introduced into the Mk 21/26 stockpile by mid-1956.[22]

Some concern was felt about the firing-switch contact buttons. These buttons were made of molybdenum and, during humidity testing, developed an insulating layer of oxide. The contacts were plated with palladium, which resisted oxide formation, but the necessary plating thickness and uniformity could not be secured, and firing tests showed that the film of molybdenum oxide would not prevent proper switch operation. Consequently, the palladium plating requirements were deleted in late October 1954.[23]

The Air Force Special Weapons Center wrote to Sandia December 15, 1954, noting that the weapon weight would be acceptable, but that efforts should be made to reduce this to the desired 15,000 pounds. A question was raised whether proximity fuzes would satisfy the military requirements for near-surface bursts, and it was recommended that a true contact fuze be developed. In this connection, it was suggested that an extendible probe-type impact device be studied.

(b)(3)

Sandia had made a study of contact fuzing and reported to the January 12, 1955 meeting of the Special Weapons Development Board. Sled and drop tests had indicated that the crystals developed for the Mk 17 Bomb would also be satisfactory for the TX-21. Also being considered was a double-shell contact device, having a false nose which contained two conductors separated by a plastic insulating layer.[25]

Report SC3608(TR), Design and Description Report at Design Release of the Mk 21/26 Mod 0 Bomb, was reviewed in the June 1, 1955 meeting of the Special Weapons Development Board. The bomb was 58.48 inches in diameter over the spoiler bands, and 149.6 inches long. (b)(1), (b)(3)

Either free-fall or parachute-retarded deliveries were possible. A 16-foot parachute furnished a 75-second time-of-fall.

The drop-test program was still under way, with nine ballistic and three fuzing and firing drops completed. Ballistic performance was satisfactory, but some parachute oscillations had been noted, and this problem was being solved as the test program progressed.

(b)(1), (b)(3)

This required an increased aircraft escape time of 100 seconds, and Wright Air Development Center was requested to develop a 24-foot-diameter parachute. It was felt that a two-stage deployment system would have to be used to mitigate the opening shock of the larger canopy.[33]

Report SC3694(TR), Engineering Evaluation of the Mk 21 Mod 0 Weapon, was presented to the December 14, 1955 meeting of the Special Weapons Development Board. Environmental resistance had been determined by component testing to performance standards, as well as overall weapon testing in arctic, tropic and desert environments. Models had been subjected to thermal tests; tests simulating loads involved in flights of B-47 and P6M aircraft; railroad humping tests; and rain, sand, dust, salt spray and sunshine tests. A total of 42 units had been drop-tested, including ballistic free-fall units, ballistic parachute units with proximity fuzes, ballistic parachute units with contact fuzes, and fuzing and firing units.

(b)(1), (b)(3)

after the safe-separation interval (determined by the setting of the arm baroswitch), the X-unit started to charge and the proximity fuzes were armed. A 3-second delay was provided by a timing device to prevent firing before the X-unit attained its normal charge.

As the bomb reached the desired burst altitude, the firing baroswitch closed, actuating the firing switch in the X-unit, discharging the capacitor bank into the detonator bridge wires, and initiating the explosive and nuclear sequence. If the system malfunctioned, the proximity fuze detonated the bomb. The parachute was deployed after release from the aircraft, if the retarded option had been selected. If a near-surface burst was selected, the barometric fuze was set at -3000 feet and the proximity fuze detonated the weapon.

(b)(1), (b)(3)

The Mk 21 Mod 0 first appeared in stockpile December 1955, and final deliveries were made in July 1956.

(b)(1), (b)(3)

The TX-26 was never authorized for production.[38]

Meanwhile, work had been proceeding on the design of a true contact fuze.[39] Report SC3606(TR), Proposed Electrical Characteristics for the Fuzing and Warhead Systems for the TX-15-X1 and the TX-21/26-X1 Weapons, was presented to the April 27, 1955 meeting of the Special Weapons Development Board.

(b)(1), (b)(3)

(b)(1), (b)(3) Drops had not as yet been made with parachute retardation, since the parachute design had not stabilized to the point where the test would be meaningful.

(b)(1), (b)(3) Due to the marginality of the data obtained, it was felt necessary to refine the test devices for an exact simulation of the weapon.[41]

The program was further discussed in the February 29, 1956 meeting of the Special Weapons Development Board.

(b)(1), (b)(3)

Sandia presented Report SC3826(TR), Design and Description at Design Release of the Mk 21/26 Mod 1 Bomb, to the June 27, 1956 meeting of the Special Weapons development Board. It was noted that the nose of this design was the same as the Mod 0 except for the impact crystal installation, and that the parachute and afterbody were identical. New contact crystals and a baroswitch were provided. The new crystals gave more consistent performance and were installed in a less critical area. The baroswitch contained four elements, ganged to make up the firing baroswitch, and these could be manually set to the desired burst altitude. Other elements in the baroswitch acted as the arming device, and these were automatically set 4000 feet higher than the firing altitude.[43] The Mk 21 Mod 1 was never produced.

Timetable of TX-22 Events

9/18/53 (b)(1), (b)(3)

10/29/53 Santa Fe Operations Office authorizes Sandia to assist in the above design.

2/2/54

(b)(1), (b)(3)

4/30/54

TX-22

(b)(1), (b)(3)

Sandia was requested to develop preliminary ballistic configurations, as well as requisite parachute ~~and~~ and fuzing and firing components.[48]

(b)(1), (b)(3)

The Santa Fe Operations Office requested Sandia, October 29, 1953, to assist the Radiation Laboratory in work on the aerodynamic case. Sandia would also design the fuzing and firing system, and conduct flight tests for both ballistics and systems prove-out.[49]

A review of a prospective drop-test program was held November 19, 1953. The devices would be released from a B-36 bomber flying at an altitude of 40,000 feet.

(b)(1), (b)(3)

The question of parachute retardation was raised, and was subsequently referred to the Air Force Special Weapons Center.

(b)(1), (b)(3)

(b)(1), (b)(3)

However, these calculations assumed that no clouds were present in the burst area to reflect thermal radiation onto the bomber and crew.

(b)(1), (b)(3)

By mid-January 1954, work on the ballistic design had progressed to the point where it was obvious that a modified TX-13 case could not be used, and the Division of Military Application authorized development of a special design.[52, 53]

(b)(1), (b)(3)

Plans were now made for test-firing.

(b)(3)

Sandia wrote to the Air Force Special Weapons Center February 15, 1954, requesting the support of the Center and the 4925th Special Weapons Group in the TX-22 ballistics test program, which would start in August 1954. Refinement of weapon parameters noted that the cylindrical case would have a diameter of 51 inches, fin box dimension of 56 inches, length (including parachute) of 145 inches, and maximum weight of 18,000 pounds. Several units would be dropped free-fall, but the majority would be parachute-retarded. The fuzing and firing signals would be provided by baroswitches, with a proximity fuze as backup.

The carrier would be the B-47 aircraft, using a reinforced TX-15 sling and rack. Both B-36 and B-52 aircraft would later be used. Plans were made for 30 tests, with early drops for ballistic and parachute study, and fuzing and firing tests starting in late 1954.[55]

(b)(1), (b)(3)

Timetable of Mk 36 Events

11/22/55	(b)(1), (b)(3)
1/3/56	TX-36-X1 design released.
4/56	Mk 36 Mod 0 enters stockpile.
5/56	Mk 21/36 Mod 1 Bomb design released.
7/13/56	TX-36-X2 program authorized for development.
9/24/56	(b)(1), (b)(3)
10/24/56	Proposed ordnance characteristics of TX-36-X2 Bomb reviewed by Special Weapons Development Board.
10/56	Mk 21/36 Mod 1 Bomb enters stockpile.
11/15/56	(b)(1), (b)(3)
4/12/57	TX-36-X2 program suspended.
4/22/57	(b)(1), (b)(3)
7/11/57	Resumption of work on TX-36-X2 authorized.
7/57	(b)(1), (b)(3)
4/23/58	TX-36-X2 design released.
1/9/59	Albuquerque Operations Office cancels Mk 36 programs.

Mk 36

(b)(1), (b)(3)

The TX-21-X1 program was subsequently canceled, but the TX-36-X1 was design-released January 3, 1956, and became, in production, the Mk 36 Mod 0.[63, 64] The weapon entered stockpile in April 1956 with a proximity fuze and internal initiator.[38]

Meanwhile, other improvements in the Mk 21 design had been suggested, principally in the fuzing and firing system. This work had begun in early 1955 in connection with the Mk 15 and Mk 39 programs, and the proposed design would provide options of either air burst or true contact firing. The weapon would be armed and fired by barometric switches, and the contact crystals would act either as primary fuze or as backup to the air-burst system. Thermal batteries would replace the nickel-cadmium units and would supply both low-voltage power for the fuzing system and high-voltage power for charging the X-unit.

Report SC3826(TR), Design and Description Report at Design Release of the Mk 21/36 Mod 1 Bomb, was released May 1956. This noted that the yield, weight, and

physical configuration of the Mod 1 was essentially identical with the Mod 0, with the exception of the fuzing and firing system. The Mod 1 would be employed in a high-altitude level release, using either a free-fall or retarded trajectory.

(b)(1), (b)(3)

Baroswitch settings were made on the ground prior to aircraft takeoff by a single dial setting. This setting was computed by comparing the intended height of burst with the target elevation above sea level and including a 300-foot offset correction. Prior to bomb release from the strike aircraft, the selector switch was placed at either air- or ground-burst position, the nuclear capsule inserted, the safing switch placed in the armed position, and the option switch placed at either the open or closed position, depending on whether ground or air burst had been selected.

The release of the bomb from the aircraft closed a pullout switch in the high-voltage-battery firing circuits, and operated magneto generators which furnished electrical pulses to ignite the low-voltage batteries. Power from these batteries was applied to the open contacts of the arm baroswitch. When the arm baroswitch closed, at the appropriate point in the weapon trajectory, low-voltage power was applied through the closed pullout switch and safing switch to the activating circuits of the high-voltage batteries, placing these latter devices in operating condition. The 2500 volts provided by these batteries charged the X-unit and supplied plate voltage to the trigger circuit.

If air-burst option had been selected, closure of the firing baroswitch applied a signal from the low-voltage batteries to the trigger circuit, thus detonating the bomb. If ground-burst option had been selected, the option switch held the firing circuit open, allowing the weapon to fall to the ground, where the contact fuze supplied the detonation signal.[65]

The Mk 21 Mod 1 Bomb was never produced, but the Mk 36 Mod 1 design entered stockpile in October 1956.

(b)(1), (b)(3)

(b)(1), (b)(3)

/The TX-36-X2 would be design-released in June 1957 with early production scheduled for July 1958 and operational availability in the fall of 1958.[69]

(b)(1), (b)(3)

On July 11, 1957, the Albuquerque Operations Office sent a teletype to Sandia, authorizing resumption of development and production activities on the TX-36-X2 program and requesting revised schedule dates, hopefully including an early production Mod-kit date of September 1958. Sandia replied, August 9, 1957, that a product definition was being prepared, and that it was hoped that the design could be released by October 1957.[81]

Report SC4113(TR), Design and Description Report at Design Release of the Mk 36Y2 Mod 1 Bomb. was issued July 1957.

(b)(3)

The TX-36-X2 became the Mk 36 Mod 2 and retrofit to this modification was planned for about half the Mk 36 Mod 1 Bombs in the stockpile. The Mod 2 incorporated a trajectory baroswitch-controlled, high-voltage safing switch to prevent inadvertent charging of the X-unit. The system also included a manually set baroswitch, desirable from reliability and operational standpoints.[83]

Sandia suggested to the Albuquerque Operations Office January 22, 1958, that Mk 36 Mod 1 Bombs which were not to be retrofitted to Mod 2 status be fitted with the safing switch.

(b)(1), (b)(3)

It was also felt that consideration should be given to the replacement of the remotely set baroswitch with a manually controlled design, since the first switch required aircraft equipment for baroswitch setting.

(b)(1), (b)(3)

It was recommended that the above changes to the Mod 1 and Mod 2 Bombs be authorized for production and that the designs be identified as the TX-36-Y1-X3 and TX-36-Y2-X3 programs. Since present planning envisaged retirement of the Mk 36 Mod 1 stockpile by mid-1960, this proposed modification would match the retirement program.[84]

(b)(3)

Report SC4222(TR), Final Evaluation of the Mk 36Y2 Mod 1 Bomb, was presented to the December 17, 1958, meeting of the Special Weapons Development Board.

(b)(1), (b)(3)

(b)(1), (b)(3)

Dynamic drop tests to ultimate loads, railroad humping tests, extreme temperature tests, and a simulated 6-month tropic storage test had been conducted, and these demonstrated the ability of the weapon to withstand these environments.[89]

At the above Board meeting, Report SC4188(TR), Final Evaluation of the Mk 36Y1 Mod 2 Bomb, was also presented.

(b)(1), (b)(3)

About half the existing stockpile of Mk 36Y1 Mod 1 Bombs would be converted to this new design, which had been called in development the TX-36-X2.

(b)(3)

The program included environmental, drop and neutron-generator compatibility tests, and demonstrated that the weapon was more than adequate to withstand the stockpile-to-target sequence. Both land and water targets had been included in the drop-test program, with release altitudes between 20,000 and 50,000 feet.[89]

On January 9, 1959, Albuquerque Operations Office canceled the Mk 36 program. The Mk 36 Mod 1 Bombs scheduled for updating would remain in current status until retirement in mid-1959.[90] This retirement program was later deferred to mid-1961.

Drogue Parachute -- A parachute that slows the rate of fall of a bomb.

(b)(1), (b)(3)

Field Command -- The local office of the Armed Forces Special Weapons Project, located on Sandia Base, Albuquerque, New Mexico.

Firing System -- The electrical system of the weapon that produces and applies a high-voltage current to the detonators.

Fuzing System -- The system that ~~signals the start of high voltage charging of the firing system.~~ arms the weapon at the appropriate time and provides a firing signal to the firing system at the selected burst height.

g -- Force equal to one unit gravity.

Gas Boosting -- The technique of increasing the yield of a nuclear device by introducing deuterium-tritium gas into the implosion process to increase the fission activity.

High-Explosive Sphere -- The ball of high explosive that surrounds the nuclear ~~primary assembly and~~ first and capsule and is designed to produces the implosion effect when detonated.

(b)(1), (b)(3)

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Knot -- A naval unit of speed, equivalent to 1 nautical mile or 6076 feet per hour.

(b)(1), (b)(3)

(b)(1), (b)(3)

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Megaton -- A measure of yield of a large weapon. One megaton is the equivalent of 1,000,000 tons of high explosive.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

Mod Kit -- A kit of parts which can be applied to a weapon to change the Mod number of the weapon.

Neutron -- An uncharged particle of slightly greater mass than the proton.

One-Point Safe Weapon -- A weapon that will not produce a nuclear yield when detonated at one point on the surface of the high explosive.

Operation Castle -- See Castle.

Operation Redwing -- See Redwing.

Oralloy -- A code term for enriched uranium. The two initial letters stand for Oak Ridge (*where Orally was first made in quantity*), *added to* alloy *from Tube* Alloys, Ltd. (the name of the British wartime atomic-energy project).

(b)(3)

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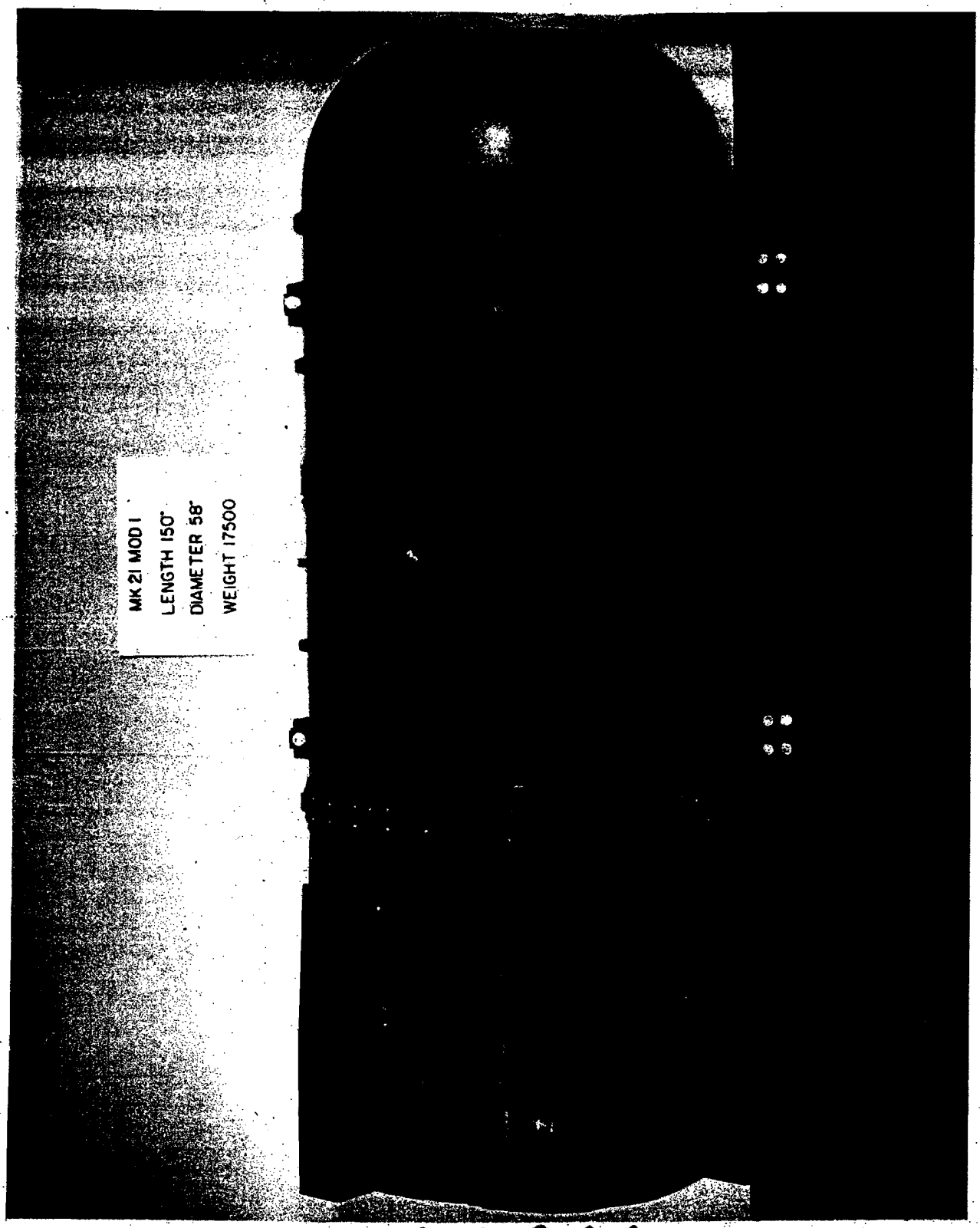
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(b)(1), (b)(3)

after the safe-separation interval (determined by the setting of the arm baroswitch), the X-unit started to charge and the proximity fuzes were armed. A 3-second delay was provided by a timing device to prevent firing before the X-unit attained its normal charge.

As the bomb reached the desired burst altitude, the firing baroswitch closed, actuating the firing switch in the X-unit, discharging the capacitor bank into the detonator bridge wires, and initiating the explosive and nuclear sequence. If the system malfunctioned, the proximity fuze detonated the bomb. The parachute was deployed after release from the aircraft, if the retarded option had been selected. If a near-surface burst was selected, the barometric fuze was set at -3000 feet and the proximity fuze detonated the weapon.

(b)(1), (b)(3)

The Mk 21 Mod 0 first appeared in stockpile December 1955, and final deliveries were made in July 1956.

(b)(1), (b)(3)

The TX-26 was never authorized for production.[38]

Meanwhile, work had been proceeding on the design of a true contact fuze.[39] Report SC3606(TR), Proposed Electrical Characteristics for the Fuzing and Warhead Systems for the TX-15-X1 and the TX-21/26-X1 Weapons, was presented to the April 27, 1955 meeting of the Special Weapons Development Board.

(b)(1), (b)(3)

All Mk 21 Bombs were withdrawn from stockpile in the period June through November 1957, and were converted into Mk 36Y1 Mod 1's.[38]

Timetable of Mk 36 Events

11/22/55	(b)(1), (b)(3)
1/3/56	TX-36-X1 design released.
4/56	Mk 36 Mod 0 enters stockpile.
5/56	Mk 21/36 Mod 1 Bomb design released.
7/13/56	TX-36-X2 program authorized for development.
9/24/56	(b)(1), (b)(3)
10/24/56	Proposed ordnance characteristics of TX-36-X2 Bomb reviewed by Special Weapons Development Board.
10/56	Mk 21/36 Mod 1 Bomb enters stockpile.
11/15/56	(b)(1), (b)(3)
4/12/57	TX-36-X2 program suspended.
4/22/57	(b)(1), (b)(3)
7/11/57	Resumption of work on TX-36-X2 authorized.
7/57	(b)(1), (b)(3)
4/23/58	TX-36-X2 design released.
1/9/59	Albuquerque Operations Office cancels Mk 36 program.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

Tritium -- The hydrogen isotope of mass number 3.

Two-Stage -- Combination of fission and fusion action in a weapon.

TX Committee -- A joint committee of Los Alamos and Sandia members, established to guide the development of implosion-type weapons.

TX-Theta Committee -- A committee established to guide the development of thermonuclear weapons.

University of California Radiation Laboratory -- A laboratory established under the guidance of the University of California to work on thermonuclear designs, and located at Livermore, California.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

X-Unit -- ~~A high-voltage transformer~~. A device used to provide high voltage to the weapon detonator.

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RS 3434/29

History of the Mk 48 Shell

The predecessor of the Mk 48 Shell was the Mk 33, an 8-inch-diameter, artillery-fired atomic projectile. While this latter shell was still being designed, the Under Secretary of the Army wrote to the United States Atomic Energy Commission, April 28, 1954, expressing interest in the possibility of developing an even smaller diameter projectile with a very low yield, and a broad study was subsequently authorized by the Secretary of Defense May 14, 1954.

The intent of this study was to investigate the possibility of using implosion techniques in an atomic artillery shell, rather than the gun method used in previous shell designs, but the state of the art was not sufficiently well advanced. Much work was, however, accomplished in the ensuing 12 months by the University of California Radiation Laboratory and resulted in a request from the Secretary of Defense to the Atomic Energy Commission, April 4, 1955, for a feasibility study of an 8-inch shell having advanced nuclear techniques. (b)(1), (b)(3)

(b)(3)

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Timetable of Mk 48 Events

4/28/54	Army expresses interest in development of small low-yield projectile.
5/14/54	Secretary of Defense authorizes study of implosion-type projectile.
4/4/55	Work by the University of California Radiation Laboratory results in request by the Secretary of Defense for a feasibility study of an 8-inch implosion shell.

(b)(1), (b)(3)

9/20/56	Assistant Secretary of Defense requests United States Atomic Energy Commission to concentrate on atomic artillery shells of 155mm (6.1 inches) diameter.
7/12/57	Assistant Secretary of Defense requests that 155mm atomic implosion projectile be developed.
5/14/58	Developmental guidelines between Atomic Energy Commission and Department of Defense for development of 155mm shell issued.

(b)(1), (b)(3)

8/4/59	Military characteristics approved by the Military Liaison Committee.
11/6/59	Sandia forwards development program definition to AEC.

(b)(1), (b)(3)

3/23/60	Military Liaison Committee suspends higher yield requirement.
1/63	Mk 48 Mod 0 Shell design released.
10/26/63	Early production of Mk 48 Mod 0 Shells.
5/64	Final development report approved and published.

Other components included a corona regulator tube, ceramic spark gap, and an inertial or setback switch. If the tube could not be designed to resist firing shock, other methods of regulation were available that could meet requirements of small size, rugged construction, and dependable operation. An extensive reliability study of the spark gap would have to be made. Due to experience gained on other designs, it was felt that the setback switch would impose no particular problems.[13]

The Army informed Sandia July 16, 1958 that, as the caliber of the implosion shell decreased, the magnitude of the associated engineering problems increased. It was therefore suggested that detailed consideration be limited to the design of a shell with a minimum diameter of 155mm. It was recommended that development engineering be authorized for a shell for the 155mm howitzer and the 175mm gun, but that general small-caliber research be continued.

(b)(1), (b)(3)

(b)(1), (b)(3)

(b)(3)

The higher yield, however, was desired and would be retained in the military characteristics.[23]

The Military Liaison Committee forwarded an amendment to the military characteristics May 2, 1960. This required that the XW-48 be compatible with M1A1 and T258 howitzers.[24] The Lawrence Radiation Laboratory and Sandia had previously informed Picatinny Arsenal that it was not possible, either through calculations or completed tests, to estimate with confidence the ability of the projectile to withstand the T258 environment, as Picatinny had indicated that this new application would subject the shell to angular accelerations 25 percent greater than previously anticipated. However, suitable tests would be conducted.[25]

These tests were subsequently made at the Army's Yuma, Arizona, test station. Linear accelerations of 12,000 g's were recorded, together with angular accelerations of 190,000 radians per second per second, the T258 howitzer environment. No premature firings were experienced, and no damage to shell components resulted. Thus, Sandia notified Albuquerque Operations Office January 15, 1961 that the T258 howitzer and XW-48 Shell were compatible.[26]

subsequently approved and published in May 1964. (b)(1), (b)(3)

It was integrated with a number of components supplied by the Department of the Army to form the XM454, an artillery-fired atomic projectile designed to be fired from 155mm howitzers equipped with either M1A1 or T258 tubes. The maximum range of the projectile was 14,000 meters, or 8.5 miles. The minimum fuze-setting range was 1650 meters, or about 1 mile, which provided safe distance from nuclear detonation. The projectile was 155mm (6.1 inches) in diameter, 34 inches (5.57 calibers) long, and weighed 120 pounds.

(b)(1), (b)(3)

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MK 25 MOD 0

(b)(1), (b)(3)

Figure 3 MK 25 Cross Section

Timetable of Mk 25 Warhead Events

3/13/51	Division of Military Application proposes that nuclear warheads be used for defense against mass aircraft raids.
2/27/52	Joint Chiefs of Staff request Joint Air Defense Board to prepare a staff study.
1/14/53	Joint Air Defense Board publishes staff study.
4/28/54	(b)(1), (b)(3)
5/7/54	Atomic Energy Commission accepts responsibility for developing a warhead for the air-to-air rocket.
5/18/54	(b)(1), (b)(3)
6/4/54	Warhead assigned designation of XW-25.
8/9/54	Joint Study Group considers details of XW-25 design.
9/22/54	(b)(1), (b)(3)
3/17/55	Assistant Secretary of Defense authorizes full development of XW-25 rocket/warhead project.
Spring 1955	(b)(1), (b)(3)
3/30/55	Military Liaison Committee requests that warheads be produced by January 1, 1957.
6/9/55	Division of Military Application requests emergency capability program.
8/24/55	Proposed ordnance characteristics report presented to Special Weapons Development Board and accepted.

(b)(3)

(b)(1), (b)(3)

7/56	Mk 25 Mod 0 Warhead design released.
12/56	Emergency capability units produced.
2/20/57	Design release report presented to Special Weapons Development Board and accepted.
6/57	Mk 25 Mod 0 Warhead enters stockpile.

(b)(1), (b)(3)

10/61	Mk 25 Mod 1 Warhead, with environmental sensing device, design released.
3/62	Mk 25 Mod 1 Warhead enters stockpile.

Atomic Demolition Munition

10/28/53	Joint Chiefs of Staff recommend development of a lightweight atomic demolition munition.
4/2/54	Military Liaison Committee releases military characteristics for the munition.
2/56	Mk 25 munition application canceled.

HONEST JOHN, JR.

9/28/54	Assistant Secretary of Defense requests Atomic Energy Commission to assist in studies of a short-range HONEST JOHN weapons system.
4/27/55	Division of Military Application proposes set of military characteristics for the HONEST JOHN, JR. adaption kit.
2/28/56	Division of Military Application cancels project.

Boosted XW-25 Warhead

7/13/56	Division of Military Application suggests development of boosted XW-25 Warhead.

8/14/56 Study of boosted warhead released. GENIE warhead compartment too small.

9/14/56 (b)(1), (b)(3)

5/27/57 Assistant Secretary of Defense requests Atomic Energy Commission to conduct feasibility study of a warhead to minimize plutonium hazards of defense rockets.

7/22/57 (b)(1), (b)(3)

11/27/57 Military requirement for boosted XW-25 Warhead canceled.

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History of the Mk 25 Warhead

As the weight of nuclear devices began to shrink and their yields to increase, it became apparent that many types of aircraft and missiles could be fitted with nuclear or thermonuclear warheads, making it at least theoretically possible for a potential enemy to saturate the defenses of the United States with a single massive attack. A system which destroyed a reasonable percentage of the attacking bombers would provide adequate defense against conventional bombs, but a relatively small number of well-placed atomic weapons could do much toward destroying an industrial complex.

There was no competent defense against such an attack; in fact, there was not even an adequate counter to the V-2 missile used by the Germans in World War II. Enemy air bases and launching sites could be destroyed, and the Strategic Air Command had assigned high priority to these targets. However, since the national policy was not to strike first, it was obvious that the country would have to be prepared to absorb the initial brunt of an all-out attack by an aggressor.[1] The Division of Military Application accordingly suggested, March 13, 1951, that some thought be given to providing a nuclear warhead to be used as a weapon of defense against mass aircraft raids.[2] Little immediate action was taken, however, since the existing state-of-the-art, both in warheads capable of high-altitude operation, and in missiles capable of achieving such altitudes with the requisite accuracy, was not sufficiently advanced.

As the capabilities of both warheads and missiles increased, the Joint Chiefs of Staff, February 27, 1952, requested their Joint Air Defense Board to study the situation. This study took place during much of 1952 and, October 29, 1952, the Military Liaison Committee notified the Division of Military Application that it was entirely possible that a

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military requirement for one or more specific weapons for air defense would be forthcoming in the near future. It was requested that the Atomic Energy Commission undertake preliminary investigation of the problems involved in developing air defense atomic warheads, with particular reference to the ability of such warheads to operate at high altitudes.[3]

The Joint Air Defense Board completed its study and released a report January 14, 1953. This report listed the various potential carriers for atomic devices, such as guns, rockets, missiles, interceptor and bomber aircraft, and recommended the use of ground-to-air missiles such as the TALOS, BOMARC and NIKE, which would carry low yield, highly economical, and efficient nuclear warheads.[1]

The report was discussed in the January 12, 1953, meeting of the Special Weapons Development Board. It was predicted that air defense warheads would have to be produced in large numbers, possibly tens of thousands, in order to provide an effective defense of any sizable portion of the country. They would thus have to be economical, both in nuclear and non-nuclear costs. These weapons would have to be operationally ready at all times to respond to a surprise attack, and they would have to be able to withstand exposure to climatic extremes ranging from the arctic to the tropics. The weapons should require only minor maintenance, since it would not be possible to provide a sufficiently large group of thoroughly trained technicians.

The Air Force BOMARC was being designed for an extended perimeter defense which would use a long-range detection system, also being developed. The range of this detection system was from 250 to 300 miles. The BOMARC range would be 125 miles, initially, with a later extension to 250 miles. The early altitude capability would be 60,000 feet, and this would be increased to 100,000 feet as enemy capabilities increased. Since BOMARC would not be operational until 1959 or 1960, a Navy missile, the TALOS-W, was planned for interim use, and would be available about 2 years before

as it was felt that these weapons had to be specialized in order to provide an immediate readiness capability, maximum economy in the use of fissionable material, and a high degree of reliability against premature detonation. Such direction was provided in a letter from Field Command to Sandia dated October 15, 1953, and eventually several air defense warhead designs were produced, the Mks 25, 30 and 31.[7]

(b)(1), (b)(3)

At the request of the TX-N Committee, Sandia studied the optimum size for warheads for air-to-air use.

(b)(1), (b)(3)

The Atomic Energy Commission wrote to the Military Liaison Committee May 7, 1954, accepting responsibility for the development of a warhead for the air-to-air rocket.

(b)(1), (b)(3)

Field Command released a set of approved military characteristics for a 15-inch warhead May 18, 1954. (b)(1), (b)(3) The warhead would be capable of remaining in a ready-to-fire condition for a period of at least 30 days. It would be able to withstand, without damage, single mission

flights of 2 hours and a total flight duration of 50 hours at altitudes up to 100,000 feet and subject to temperatures ranging from -90°F to +165°F. Resistance to accelerations of ±100 g's along the longitudinal axis, ±20 g's along any perpendicular axis, and angular accelerations of 400 radians/second/second would be required. The firing system would be able to operate to an altitude of 100,000 feet.[11]

At the request of the TX-N Committee,[12] the designation XW-25 was assigned to the warhead June 4, 1954.[13] The Division of Military Application noted that the Air Force would be responsible for the ballistic case, arming and fuzing system, power supply, propulsion system, and associated assembly, test and handling equipment. The Atomic Energy Commission would provide the implosion warhead, including nuclear capsule, pit, high-explosive system, detonators, cables, X-unit, firing switch, nuclear insertion gear, sphere case, and associated assembly, test and handling equipment.[14]

The missile was given the code name of DING DONG, and a Joint Study Group named, with representatives from the Air Force Special Weapons Center, Armed Forces Special Weapons Project, Los Alamos, and Sandia, and this group initially met August 9, 1954. The weapon would be optimized for the F-102 interceptor, with secondary applications to the F-86, F-89 and F-100 aircraft. The Air Force Special Weapons Center was assigned overall responsibility for the weapon system, with the assistance of Wright Air Development Center.

The outer diameter of DING DONG, exclusive of fins, would be about 16.5 inches, but excursions to 15 and 18 inches would be investigated to determine their influence on performance. The total length of the weapon would be compatible with the launching restrictions of the applicable bomb bays. The use of both fixed and folding fins would be considered. If a reversible actuating mechanism for fin extension and retraction was provided, it would be capable of repeated operation while the weapon was being externally carried at air speeds up to 250 knots. If an automatic,

one-time fin operating device was used, its probability of operational failure was not to be greater than 1 in 10,000. This mechanism would have to operate at speeds up to Mach 1.5 and at altitudes up to 35,000 feet.

There would be three sequential signals required to detonate the warhead; one to actuate the nuclear arming mechanism, another to initiate electrical arming, and a third to provide the firing signals. The fuze would include a safe-separation feature to prevent premature warhead detonation. A detonation timing element, capable of being preset before aircraft takeoff, would be designed. The rocket would have a 2500 feet per second (1700 miles per hour) velocity increase over its aircraft speed and a flight time of 15 seconds to target. The weapon would be used tactically at all altitudes up to 50,000 feet.[15]

(b)(1), (b)(3)

A study of kill versus yield was made by the Joint Study Group, and published November 30, 1954.

(b)(1), (b)(3)

With the larger weapons, the launching range had to be increased to provide enough escape time. This increase in range decreased the probability of target detection, and more than offset any increase in effectiveness.

(b)(1), (b)(3)

In respect to the warhead diameter, the cost per kill in terms of nuclear material was less in the largest diameter studied, which was 18 inches. However, larger diameters would require corresponding increases in the size and weight of the carrying rocket and would cause aircraft compatibility problems. The recommended diameter was 17.25 inches.

(b)(1), (b)(3)

The study indicated that it would be desirable to provide a missile velocity increase of 3000 feet per second during the rocket flight and, since missile contractors had indicated that this would be possible, it was recommended that the rocket and warhead be designed to this specification.

The design criteria required that the warhead be considerably different than previous designs. It must be able to withstand 100 g's, it must be light so as to attain high velocity, it must be capable of being carried at high altitudes for many hours and still operate, and it must be capable of withstanding the very high temperatures generated in high speed flight.[17]

The Joint Study Group was later dissolved and reconstituted as the Air-to-Air Rocket Joint Project Group, and held its first meeting under the new title January 31, 1955. The warhead weight, by the latest estimate, was about 230 pounds, and Douglas Aircraft Company, which was to provide the rocket, was requested to design to this figure. The Group recommended that the warhead thermal battery be made an integral part of the X-unit and sealed into this package. An arm/safe switch, capable of being monitored, and located in the X-unit charging circuit, would be operated either automatically or manually.[18]

The Assistant Secretary of Defense, March 17, 1955, authorized full development activities on Project DING DONG. The Armed Forces Special Weapons Project would have normal responsibilities, but the Air Force would possess overriding authority within the Department of Defense during the development period.[19]

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Sandia notified Santa Fe Operations Office March 18, 1955, that the Military had indicated an urgent desire to have the DING DONG weapon operational by 1957. Since this meant that an appreciable number of weapons would have to be available at that time, it was requested that an authorization for quantity production be released.[20] The Atomic Energy Commission replied that since no firm production directive for the XW-25 Warhead had been received, it was premature to authorize production.[21]

(b)(1), (b)(3)

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(b)(1), (b)(3)

The Military Liaison Committee wrote to the Atomic Energy Commission March 30, 1955, requesting that the small atomic warhead be developed in time to match a predicted rocket availability date of January 1, 1957. This required that the warhead be ready for operational suitability tests by July 1, 1956. It was noted that feasibility studies were being made of this warhead for use in other applications, such as a demolition munition, but these studies were not to interfere with the urgent need for the air-to-air capability.

The warhead would be rugged, reliable, and easily installed and tested; it would be safe to transport and handle; and easy to use in combat. It would provide maximum interchangeability of nonnuclear components between it and other atomic warheads, although this requirement was not to preclude development of a sealed design.

(b)(1), (b)(3)

The diameter of the warhead would be 17-1/4 inches, and the weight and length would be held to a minimum.

The warhead installed in a weapon would be capable of storage in the ready-to-operate condition for a period of at least 30 days, but extension of this time to 90 days was desired if it could be attained on a not-to-delay basis. The warhead would be operable at altitudes up to 75,000 feet, with 100,000 feet as an ultimate goal. It would withstand temperatures and accelerations specified in the military characteristics.

(b)(1), (b)(3)

Santa Fe Operations Office notified the Division of Military Application April 15, 1955, that Sandia was planning system flight tests of the XW-25 between November 1955 and August 1956, warhead design release in March 1956, and early Mark-quality units delivered to War Reserve by mid-1957. This schedule could be accelerated if flight test rockets could be provided at an earlier date.[24]

Some concern had been felt over incorporating thermal batteries in the warhead. It was felt that this prevented nuclear safing, allowed components essential for full-scale nuclear detonation to be continuously present, and permitted the squibs of the batteries to be initiated by fire or any external radio frequency device. A careful evaluation was made and a report issued April 28, 1955, which described several methods of safing. These included removal of the batteries from the warhead, a safety device in the battery circuit, a thermally-operated switch to open the circuit in the event of fire, late arming switches in the high-voltage circuits, or an arm/safe switch in the warhead or adaption kit.

The first two methods would not contribute to the safety of the overall weapon. The thermally-operated switch would protect against only one type of failure. Late arming switches would have to be low-energy devices, and would be heat-sensitive. The arm/safe switch was thus selected for use. If this was located in the adaption kit, a high-voltage line would have to be extended from the sealed warhead compartment to the adaption kit. However, if the switch was placed in the warhead, it would be protected by the warhead seal and could be placed on the high side of the X-unit where it could also be used to short out the battery or capacitor and improve the safety margin. This switch would be actuated automatically, to guard against any possible degradation in reliability due to pilot error.[25]

The Air Force issued a report on the arming and fuzing system for the air-to-air rocket April 28, 1955. Three systems had been analyzed, and it was concluded that one with an arming plug and a monitored switch in

the warhead would have the least probability of premature detonation during storage. It was also concluded that protection against premature detonation before safe separation would be adequate if a thermal switch was provided.[26]

(b)(1), (b)(3)

Since high volume warhead production was anticipated, it was planned to delay production until much of the developmental and operational testing had been completed, in order to prevent any extensive retrofit. Thus Mark- quality warheads would not become available in quantity until September 1957.[27]

The Military Liaison Committee replied, May 19, 1955, that rocket development had been committed to a capability date of January 1, 1957. Initial application would be to 25 modified F-89 aircraft (which had replaced the F-102 due to a delay in the latter airplane), and which were to be available by late 1956.

(b)(3)

The DING DONG rocket design now began to take final shape, and was described in a letter from Field Command May 24, 1955. This unguided rocket would have a range from 3 to 5 miles, with an average incremental velocity of 3000 feet per second over its launch speed. The rocket could operate at altitudes up to 60,000 feet, but would be limited by interceptor performance, safe-escape range, radar detection angles, and angle of attack.

The overall length of the rocket (including warhead assembly) would be 114 inches, its maximum outside diameter, exclusive of fins, 17.25 inches, and its gross weight 807 pounds. The diameter with fins retracted would

were used to prevent running wires through the sealed portion of the warhead.

The primary aircraft carrier would be the F-102, which would be operationally available in late 1957. Since the intercept problem was complex, the pilot used an automatic fire-control system to launch the missile. This control system detected the target, provided course steering information to the aircraft pilot, and launched the weapon in accordance with a predetermined fuze setting.

(b)(3)

The nuclear system was hermetically sealed, thus eliminating corrosion problems.

The only handling equipment required for the warhead was a shipping container. Two testers would be provided; one to check the integrity of the warhead seal, and the other to test continuity in the thermal battery initiation circuit and monitor the position of the arm/safe battery switch. Since use of the weapon might be required at short notice, no preflight testing would be necessary. Periodic checks would, however, be made, ranging from a 30-day pressure seal check to an 18-month teardown to check the effects of aging on interior components.

Design release of the warhead was scheduled for July 1956, and a number of production units would be delivered by June 1957. The report was accepted by the Board and forwarded to the Division of Military Application.[32]

(b)(1), (b)(3)

sea level to 60,000 feet, with flight times (depending on altitude) of 5-1/2 to 12 seconds, and which were determined by the requirements for safe separation from the delivery aircraft. The GENIE weighed 800 pounds, was 115 inches long, and 17.5 inches in diameter.[37]

The Mk 25 Mod 0 Warhead had been design-released in July 1956, and stockpile entry effected in June 1957. The emergency capability units were completed on schedule.

(b)(1), (b)(3)

The warhead was sealed and pressurized to 15 pounds per square inch on assembly, to prevent arc-over of high voltages at high altitudes. Capability was established with the F-89 aircraft, with later application to the F-101 and F-106 as these became available.

Operation of the weapon was as follows: A ground-control center located an approaching enemy aircraft and directed the interceptor to it. The target was located on the interceptor's fire-control system, which provided attack information to the pilot. After the pilot switched to the special weapons option and the radar locked-on to the target, the fire-control system operated the arm/safe switch to the arm position. Subsequently, a capacitor used to fire the low-voltage thermal batteries in the fuze was charged and a timing signal issued.

The weapon was launched automatically by the fire-control system when the interceptor entered the correct position at the proper range, which was dictated primarily by radiation safety considerations. At launch, an acceleration switch opened and inertial switches closed and latched to fire low-voltage thermal batteries. The timer then started to operate. At burnout, about 2 seconds after launch, the acceleration switch closed, firing the warhead high-voltage thermal batteries, and charging the warhead capacitors. When the timer completed its rundown, the weapon

detonated. If the target was lost before launch, the arm/safe switch automatically returned to the safe position, and it could be subsequently rearmed or resafed as many times as necessary.

The successful completion of the program was greeted with enthusiasm by the Air Force, and Sandia was complimented on its part of the work.[38] The W25-0 was hailed as the first of a group of weapons that would require little inspection and would be called "wooden bombs," so termed because it was hoped their maintenance would be only that of a block of pine.

(b)(1), (b)(3)

Report SC4190(TR), Engineering Evaluation of the Mk 25 Mod 0 Warhead, was issued August 1958. The system environmental and initial flight test program had been successfully completed. Flight tests had proven compatibility of the warhead with the MB-1 or GENIE rocket, and resulted in certification of the F-89 aircraft as a carrier. Flight tests were continuing to prove compatibility of the weapon system with F-101 and F-106 aircraft.

A series of seven airdrop and five sled tests had shown that a charged X-unit would not discharge upon impact unless a firing signal had been received by the fuze, but that an armed fuze would probably fire. Thus, the probability of a nuclear detonation was high if a GENIE struck the ground with an armed fuze and X-unit. However, the probability of an air dud in such cases was low, since the primary cause of an air dud was an arming failure.[39]

The Division of Military Application authorized the installation of environmental sensing devices in the Mk 25 Warhead, and this information was furnished to Sandia by the Albuquerque Operations Office January 30, 1961.[40] Sandia subsequently designed the Mk 25 Mod 1 Warhead which was released October 1961 and entered stockpile March 1962. This change provided an inertial switch which was installed in the high-voltage battery activation circuit of the X-unit and prevented inadvertent operation of the warhead firing set until the warhead had experienced a launch acceleration.[41]

Atomic Demolition Munition

The Joint Chiefs of Staff recommended to the Secretary of Defense, October 28, 1953, that a lightweight atomic demolition munition be developed. On November 3, 1953, the Assistant Secretary of Defense requested that the Armed Forces Special Weapons Project coordinate a statement of suitable military characteristics for such a warhead 15 inches in diameter, 30 inches in length, and weight not over 200 pounds.

(b)(1), (b)(3)

The weapon would have a readiness period of 30 days, and be capable of disassembly into 40-pound packages.[42]

(b)(1), (b)(3)

Little work was done on the project, however, and the application was canceled in February 1956 in favor of similar devices on the Mk 30 and Mk 31 programs.[44]

HONEST JOHN, JR.

The Assistant Secretary of Defense notified the Atomic Energy Commission September 28, 1954, that the Army had initiated studies of an HONEST JOHN, JR., or short-range HONEST JOHN, weapons system, and wished to include an atomic capability with the XW-25 Warhead. It was requested that the AEC help in the project, but not to interfere with the high-priority development of the air-to-air application of this warhead.[45]

The proposed military characteristics for an adaption kit for this system were released by the Division of Military Application April 27, 1955.[46] These called for a small, implosion-type atomic warhead with a diameter from 15 to 17 inches. The weapon would be a surface-to-surface rocket fired from two types of launchers; a self-propelled and a lightweight helicopter-transportable version.

(b)(3)

The fuzing system would provide a signal to the warhead after a preset time had elapsed and a preset velocity had been attained. Again, little work was accomplished, and on February 28, 1956, the Division of Military Application notified Santa Fe Operations Office that the Army had discontinued plans for the above application, in favor of a warhead with a higher yield and small diameter.[44]

Boosted XW-25 Warhead

The Division of Military Application, July 13, 1956, noted that the Department of Defense had informally expressed concern about the lack of a boosted XW-25 Warhead.[47] Albuquerque Operations Office replied, in a teletype of July 25, 1956, that no formal interest in such a warhead had ever been stated, nor had the Laboratories been requested to undertake this development. The need for such a warhead was questioned, and it was requested that information be supplied as to whether this was due to a desire for nuclear economy, higher yield, or concern about plutonium contamination.[48]

The Division of Military Application responded, July 30, 1956, noting that the military request resulted from a study prepared at the request of the Joint Chiefs of Staff.

(b)(1), (b)(3)

This study was released August 14, 1956. It was noted that the GENIE rocket warhead compartment was not large enough to accommodate boosting equipment and that the development of a suitable system would result in an entirely new weapon design.[50]

(b)(1), (b)(3)

The Division of Military Application wrote to Los Alamos September 14, 1956, noting that a possible plutonium hazard would be created by the XW-25 when making peacetime intercepts of unidentified aircraft. Additionally, the Air Force had requested that a study be made of the feasibility of producing warheads containing only uranium-235, to reduce the hazards to civilian populations and air bases from contamination caused by one-point detonations or fire.

(b)(1), (b)(3)

A Joint Feasibility Group was convened, which reported November 9, 1956. This Group had examined several different types of nuclear designs, and noted that an implosion warhead containing only uranium-235 would ease the contamination problem, but that complete elimination would be possible only through use of a gun-type design. Radiological contamination was currently of much interest, and attempts were being made to minimize the hazards associated with the transportation, storage and use of atomic weapons.[53]

Subsequently, May 27, 1957, the Assistant Secretary of Defense directed the Atomic Energy Commission to cooperate with the Armed Forces Special Weapons Project and the Services in a feasibility study of an atomic warhead that would minimize the plutonium hazard of defense rockets. without unduly increasing the nuclear material costs.[54]

(b)(1), (b)(3)

(b)(1), (b)(3)

Safe-Separation Time -- A time interval provided by a timer to allow safe escape of an aircraft delivering a weapon before the weapon detonates.

Safing -- Putting a weapon in condition such that it cannot fire.

Santa Fe Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with the Sandia operations.

Sealed Pit -- A weapon in which all the nuclear components (except the boosting gas, when used) are permanently installed in place. Designed to eliminate the need for inflight nuclear insertion mechanisms.

Services -- The Department of Defense.

Special Weapons Development Board -- A joint Sandia-Military board at Sandia Base to provide local guidance on weapons design.

Squib -- A device containing a small powder charge. When detonated, the resulting gas pressure closes a switch or performs a similar action. A light, quick-acting, one-shot device.

Strategic Air Command -- A part of the United States Air Force devoted to the attack of strategic targets, such as industrial plants.

Teapot -- A less-than-full-scale test series held at the Nevada Test Site. Series of 14 tests, starting February 18 and ending May 15, 1955.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

Tritium -- The hydrogen isotope of mass number 3.

Two-Stage -- Combination of fission and fusion action in a weapon.

TX-N Committee -- A joint committee of Los Alamos Scientific Laboratory and Sandia members, established to guide the development of implosion-type weapons.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3 percent uranium-238; the rest is uranium-235.

Warhead -- A weapon carried to the target by missile.

Wooden Bomb -- A weapon designed to have an infinite shelf life and to require no special storage or surveillance. "As trouble-free as a block of pine."

X-Unit -- ~~A high-voltage transformer.~~ A device used to provide high voltage for the weapon detonators.

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AEC ATOMIC WEAPON DATA
Sigma 3

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"HISTORY OF THE MK 27 WEAPON (U)"

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Weapon Systems

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Timetable of Events

Mk 27 Weapon

Late 1953 Plans made to develop a small, two-stage weapon.

(b)(3)

8/5/54

(b)(1), (b)(3)

6/6/55

7/6/55 Division of Military Application assigns Mk 27 development to Radiation Laboratory and Sandia-Livermore.

8/9/55

(b)(1), (b)(3)

6/27/56 Special Weapons Development Board discusses proposed ordnance characteristics of the TX-27 weapon.

(b)(1), (b)(3)

8/21/57 Mk 27 Bomb design released.

10/21/59 Final evaluation report of Mk 27 Mod 0 Bomb presented to Special Weapons Development Board and accepted.

Mod 1

6/22/59 Division of Military Application proposes that manual arming capability of the fuzing system be deleted.

9/28/59 Sandia provides ready-safe switch for above purpose, creating the Mk 27 Mod 1.

Mod 2

10/21/60 Sandia proposes that a squib-actuated switch be replaced with a solenoid actuated design, to prevent activation of the squib switch by radio-frequency energy. This resulted in the Mk 27 Mod 2 design.

REGULUS Warhead Application

5/21/55 (b)(3)

8/12/55 Sandia submits proposed scope of work for adaption kit for XW-27/ REGULUS I.

1/25/56 Special Weapons Development Board discusses proposed ordnance characteristics of the XW-27 Warhead and its missile applications.

3/27/57 W27/REGULUS I design released.

4/23/58 Final engineering evaluation of the Mk 27 Mod 0 REGULUS I Warhead Application presented to and accepted by the Special Weapons Development Board.

RASCAL Warhead Application

Mid-1955 Missile considered for XW-27 application.

1-57 Application design release issued.

4/23/58 Final engineering evaluation of the Mk 27 Mod 0/GAM-63A (RASCAL) Warhead application presented to and accepted by the Special Weapons Development Board.

B-58/HUSTLER Application

Summer 1953 Feasibility study of XW-27/B-58 proposed.

1/18/56 Project authorized for design.

6/57 Project canceled.

TRITON Warhead Application

8/54 Feasibility study for XW-27/TRITON authorized.

12/9/55 Project canceled.

MATADOR Warhead Application

12/16/54

(b)(3)

11/56 XW-27/MATADOR project canceled in favor of XW-28/MATADOR.

SHAPE 96 Warhead Application

1/12/55 Air Force Special Weapons Center states that project appears feasible.

5/24/55 Santa Fe Operations Office authorizes full development.

3/56 Project canceled.

HISTORY OF THE MK 27 WEAPON

In late 1953, as the design of the TX-15 began to crystallize, it became evident that major weight and size reductions of thermonuclear devices were possible.

(b)(1), (b)(3)

The weapon would be carried by the Army REDSTONE missile; the Navy REGULUS I, REGULUS II, and TRITON; and the Air Force B-58 Pod, MATADOR, SNARK, RASCAL and NAVAHO. The bomb weight was not to exceed 3000 pounds. It was to be capable of either internal or external carriage on the Navy AJ, A2U, A3D, A4D, F3H, F7U, P6M and F2H; and the Air Force B-47, B-52, B-57, B-66, F-84, F-100, F-101 and F-105.

The bomb would be able to withstand, without damage or functional impairment, forces and accelerations caused by catapulted takeoffs, arrested landings, ejection, and normal flight maneuvers. A surface-burst contact fuze was desired, selectable in flight as a primary burst option, but a radar fuze producing a near-surface burst would be acceptable if a true contact fuze could not be achieved. An air-burst fuze would be capable of being set to the desired burst height after takeoff, and a contact or near-surface fuze would provide cleanup. The weapon would be capable of remaining in a ready-for-use condition for as long a period of time as possible, but not less than 30 days.[3]

(b)(1), (b)(3)

(b)(3)

It was hoped that the devices would be produced in late 1956, by which date suitable delivery aircraft would be available. It was felt, however, that if a maximum bomb weight of 3000 pounds was maintained, the warhead weight might be less than the specified 2800 pounds, and that it would have a correspondingly lower yield. However, if the warhead weight was maintained at 2800 pounds, the bomb weight would probably exceed 3000 pounds. The Los Alamos Scientific Laboratory wanted as large a warhead diameter as possible, while Sandia hoped that the diameter could be kept to a minimum to ease external carriage problems.

This discussion was continued in the September 17, 1954 meeting of the TX-Theta Committee. Weapon diameters from 20 to 35 inches were examined, together with five general shapes. As indicative of the penalties created by external carriage, it was noted that a store with a diameter of 30 inches and a weight of 3000 pounds could be carried by the F-100C. If this weight were increased by 500 pounds, the ceiling of the aircraft would be reduced 500 feet and its range shortened 20 nautical miles. The drag of such an external store was almost 20 percent that of the airplane, and this drag increased about 30 percent if the bomb diameter were increased 5 inches.

(b)(3)

Delivery studies had been made by Sandia.

(b)(1), (b)(3)

The use of a safe-separation timer to provide adequate aircraft escape time after release was recommended.[5]

(b)(1), (b)(3)

(b)(1), (b)(3)

The reasons behind this proposal were that missiles could accommodate warheads up to 44 inches in diameter, but this size was incompatible with external carriage on most aircraft. External aircraft carriage considerations dictated that a bomb with a diameter close to 30 inches be used, and having a structure that could withstand lug and sway brace loads. Additionally, in view of the present circular error inherent in missiles, it was felt advisable to provide a missile warhead with the highest possible yield.[7]

This proposal was forwarded to the Santa Fe Operations Office November 17. 1954.

(b)(1), (b)(3)

It would be compatible with the missiles intended as carriers for the XW-5 Warhead, although some minor warhead compartment modifications might have to be made.

(b)(1), (b)(3)

(b)(1), (b)(3)

This was followed by another letter, March 24, 1955, noting that production interest would depend on the yield attained.[9]

(b)(1), (b)(3)

A meeting was held June 6, 1955, with representatives of the University of California Radiation Laboratory and Los Alamos present, and resulted in a suggestion that Livermore produce the weaponized version of the XW-27.

(b)(1), (b)(3)

(b)(1), (b)(3)

The use of an unboosted primary was discussed in a teletype from the Radiation Laboratory to the Division of Military Application July 1, 1955.

(b)(3)

The shape selected was a reduced-scale Mk 15, with a diameter of 30-1/4 inches and a length of 115 inches, and was chosen due to the proven ballistic and fuzing characteristics of the Mk 15.

(b)(1), (b)(3)

Santa Fe Operations Office notified the Division of Military Application July 13, 1955, that the XW-27 case design posed extensive new engineering problems, and that any predicted time scales would have to be viewed with somewhat less than normal confidence. However, the Radiation Laboratory and Sandia were hopeful of freezing the design by January 1, 1956.[15]

The bomb weight would be kept to a minimum. It would be internally carried in the Air Force's B-47, B-52 and B-66; and in the Navy's AJ, A3D, A3J and P6M. A surface-burst contact fuze was required, which could be selected in flight as the primary burst option, or rendered inoperable prior to flight. The height of burst in the air-burst option would be as near one fireball radius above the target as possible.[18]

The Division of Military Application wrote to Santa Fe Operations Office September 13, 1955, requesting that the Radiation Laboratory and Sandia proceed jointly in the XW-27 program. An operational availability date of October 1957 was desired, provided that this could be met without interference to other programs.[19] Subsequently, September 23, 1955, Santa Fe Operations Office authorized full-scale development for the TX-27 internally carried bomb and the XW-27 warhead programs.[20]

(b)(1), (b)(3)

(b)(1), (b)(3)

It was felt that the bomb design could be released in April 1957, with early production about one year later. The bomb requirements would not adversely affect the nuclear performance of the warhead. The bomb might have a maximum diameter of 30-1/4 inches, an overall length of about 125 inches, and a weight of 3300 pounds. Since the case would be relatively weak, strong handling points would have to be provided.[22]

Sandia notified Field Command December 22, 1955, that the Military Characteristics for the TX-27 designated the same carrying aircraft as for the TX-15, with the exception of the A3J. This similarity in diameter and length of the two weapons had prompted studies aimed at use of the TX-15 suspension system with as little change as possible. It would be necessary to reinforce a large portion of the weapon, and the effect of this reinforcement on weapon yield would have to be determined.

(b)(1), (b)(3)

The Services were requested to submit requirements for aircraft bomb suspension, both for a drop-test program and to allow evaluation of the case design from the standpoints of strong areas and structural requirements.[23]

By early 1956, it had been decided that thermal batteries would be used. It was felt that a barometric fuze would be suitable for the air-burst option. A safe-separation device would be necessary, since some of the aircraft designated as carriers would release bombs at low altitudes.

A trajectory arming device would be included to minimize the possibility of detonation during ground handling or takeoff accidents. The use of air scoop, differential pressure, ram pressure, spin, or roll integration had been considered, and a squib-initiated differential-pressure device being developed for the TX-28 appeared promising. A mechanical clock timer, also being designed for the TX-28, could be used if a timer were required, but its contacts closed only for a 3-second period and continuous closure would have to be provided by a hold-down device. A manually adjustable baroswitch, used in the TX-15, should be suitable for arming and firing, and would provide a close-arming capability.[24]

(b)(1), (b)(3)

The impact fuze was tested to determine whether rain or hail would cause premature or accidental operation.

(b)(1), (b)(3)

The number and location of the contact-fuze elements were slightly changed, to provide better impact response. Sled tests were felt to be unnecessary, and were canceled.[32]

Report SC3776(TR), Proposed Ordnance Characteristics of the TX-27 Weapon, was discussed in the June 27, 1956 meeting of the Special Weapons Development Board. The weapon was described as an internally carried, free-fall bomb,

30-1/4 inches in diameter, 128 inches long, and about 3200 pounds in weight. The weapon consisted of a nose case, warhead, fuze compartment, rear case section with fins, and split band joining the fuze and warhead sections. All compartments were sealed against the weapon environment, with the exception of the split-band and rear-case areas which ~~contained~~ contained no critical components. The weapon could be carried in the Air Force B-47, B-52 and B-66; and the Navy AJ, A3D, A3J and P6M. The A3J application involved replacement of the weapon tail by two fuel tanks, each 30 inches in diameter and 100 inches long, and the overall length of this configuration was about 300 inches.[33]

Meanwhile, difficulty had been encountered in trying to reduce the weight of the weapon. The Military Liaison Committee, on July 5, 1956, noted that a weight increase of 300 pounds over the military characteristics could be tolerated, but would be accepted only on an interim basis.

(b)(1), (b)(3)

Sandia and the Radiation Laboratory jointly reported to the Division of Military Application August 10, 1956, that it would not be possible to reduce the weight of the warhead to 2800 pounds and maintain the yield, and an increase of 100 pounds was mandatory.

(b)(1), (b)(3)

Compatibility problems were also given attention. Multiple carriage of the TX-27 Bomb in the P6M and A3D aircraft was proposed. The bomb fin span precluded carriage of more than one weapon in the A3D, and Sandia investigated the possibility of reducing this fin span. Suitable shapes were tested in the wind tunnel, and it was felt that the fins could be satisfactorily contained within a box whose sides were tangent to the major diameter of the bomb, although the bomb length would have to be increased to 142 inches over its current 125 inches.[36]

Studies had been made of suitable shapes for external carriage, and one with a diameter of 30-1/4 inches, length of 250 inches, and weight of about 3300 pounds was suggested. It was found that this shape was suitable for use with the F-101, F-107, F-108 and RB-47, but was not compatible with the A4D.

Performance degradation, even with semisubmerged carriage, would reduce the top speed of the F-101 approximately 100 knots and that of the F-107 about 20 knots, with the range of both aircraft being shortened some 100 nautical miles. Carriage on the RB-47, using fuselage elbow pylons, would reduce airplane performance about 5 knots and would affect the range slightly.[37]

By early October 1956, wind-tunnel tests of the 125-inch shape had indicated that this configuration was fairly stable. However, the barometric pressure ports would have to be located in the rear case between the fins. This location could not be used on the A3J, as the weapon tail would be replaced by the fuel tanks.

Since a barometric port common to both configurations was desirable, studies were made of a modified Mk 16 shape 142 inches long, having a small box fin, and it was found that a common baro port could be developed. Test data indicated that a spoiler band at Station 82, which was required for the 125-inch shape, was also suitable for the longer case. A change to the longer length would thus provide compatibility with the B-57 and allow multiple-carriage for the A3D and B-66.[38] Air Force requirements for external carriage were canceled October 12, 1956, when the F-101 and RB-47 were eliminated, but the bomb length was left at 142 inches.[39]

Provision for both sling and lug suspension was requested in mid-1956, to provide added operational flexibility.[40] Sling suspension had already been designed, and Sandia subsequently provided removable lugs. The Air Force deleted all TX-27 carriers, except the B-47 and B-52, in December 1956, and these used sling suspension only.[41] However, the Navy required lug suspension for the A3D, and the capability was left for this application.[42]

(b)(1), (b)(3)

The Mk 27 Mod 0 Bomb was design released in May 1957 and achieved production in October 1958. Report SC4091(TR), Description and Status Report at Design Release of the TX-27 Bomb, was presented to the August 21, 1957 meeting of the

(b)(3)

The signal that triggered the high-voltage battery squibs had to be received about 2-1/2 seconds before weapon detonation, to permit charging the X-unit.[48]

The operating sequence of the TX-27 Bomb was as follows: The selector switch in the aircraft was moved to either the air-burst or the ground-burst position, thus placing the low-voltage arm/safe switch in operating position. As the bomb was released, pullout wires activated pulse generators, and this brief pulse of power was applied to a transformer. This pulse transformer had two primary windings, either of which could supply enough energy to fire all the battery squibs. One transformer secondary was connected to a squib-operated monitor switch that fired simultaneously with the battery squibs. This monitor switch provided a simple continuity test for the battery condition; if the switch was open, the batteries had not been activated.

(b)(3)

If air-burst option had been selected, weapon detonation occurred when the firing baroswitches closed. This firing was accomplished by pulsing the trigger transformer, thus operating the thyratrons, causing the gap to break down, and connecting the output of the X-unit capacitors to the detonators of the primary. The output of the primary then compressed the secondary and initiated the fusion reaction.

If ground burst option had been selected, the impact crystal network, operating through the secondary of the saturable core transformer, supplied a voltage pulse to the thyratrons which, in turn, fired the X-unit. If a ground burst signal had been given to the transformer, with the core having been driven to saturation in a given direction, and then the air-burst signal supplied, the weapon would not fire, as there would not be enough change in flux to pulse the transformer. As the bomb continued to fall in its trajectory, however, there would be a detonation when it struck the ground, since the contact burst signal would fire the circuit. In the event the air-burst signal did not operate properly, the ground burst signal would provide backup. The contact fuze network could be disconnected for contact preclusion.[49]

The Division of Military Application sent a teletype to Albuquerque Operations Office, June 22, 1959, noting that manual operation of the arm-safe switch was required and suggesting that action be taken to provide a safer design.[50] Sandia proposed a change, September 28, 1958, which would replace the arm-safe switch with a ready-safe design, operable only by remote control. This would decrease the possibility of sabotage or willful destruction of the Mk 27.[51] The proposal was accepted and resulted in creation of the Mk 27 Mod 1 Bomb.

Sandia subsequently proposed another change, October 21, 1960, which would replace a squib actuated switch in the Mk 27 Bomb and Warhead with a switch that was solenoid operated.[52] It had been found that recent developments in communication transmitters had resulted in higher radio frequency energies being used. This amount of energy, it was felt, might activate the squib switch.[53]

The change was incorporated and resulted in development of the Mk 27 Mod 2 Bomb and the Mk 27 Mod 1 Warhead. Report SC4925(WD), Final Evaluation of the

The adaption kit would permit storage for a period of at least 5 years, and be capable of reliable operation after being installed in the missile for 75 days. The weight of the adaption kit would be a minimum, with the gross weight of kit and warhead not exceeding 3000 pounds.[58]

On August 12, 1955, Sandia submitted a proposed scope of work for the development of the adaption kit for the XW-27/REGULUS I. The first kit would be available for flight testing in March 1956, and complete design release would be in January 1957.[59] This scope of work was approved August 26, 1955.[60]

Early design studies showed that all the possible configurations of the XW-27 which was acceptable from the physics standpoint would result in interference with the REGULUS I air scoop. Agreements were reached to modify the air scoop.[61]

Sandia informed the Bureau of Ordnance September 2, 1955, that the development of a continuously adjustable safe-separation timer would require 3 months of development effort. If, however, the timer requirements could be revised to specify only a capability for either 2 or 10 minutes, the complexity of the device would be reduced, and development time and cost would be saved.[62] This suggestion was adopted.[63]

A radar fuze had been proposed for air burst, but Sandia noted that the required 600-foot accuracy in burst height could be attained with a barometric fuze. This fuze would eliminate any electronic countermeasures problem, simplify assembly and preflight procedures, and reduce weapon support.[62]

The operational characteristics of the XW-27 Warhead required that nuclear and electrical arming be performed shortly before weapon burst. This obviated the need for command arming, since arming would not occur until the weapon was definitely committed. This requirement would also eliminate the need for automatic arming at the end of safe-separation time.[62]

Details of the adaption kit now became firm. Thermal batteries would provide power to charge the X-unit. The primary would be gas-boosted, and the adaption kit

would supply signals to arm and initiate warhead operation. The fuze would be baroswitch-operated, with contact crystals furnishing backup. This fuze would also be capable of accepting radio-command arming and firing signals.

The safe-separation timer would be started by closure of an acceleration switch at missile launch. Additional safety would be provided by a device to connect the thermal battery to the X-unit only after the arming signal had been received. The warhead dimensions were 30-1/4 inches in diameter, 70-1/2 inches in length, and 2800 pounds in weight.

By the end of 1955, a close-arming concept had been adopted, to minimize premature detonation by activation of the impact crystals through enemy antiaircraft fire. This was accomplished by setting the arming baroswitch to operate only a short distance above the firing baroswitch.

(b)(3)

Sandia discussed the adaption kit for the XW-27/REGULUS December 23, 1955. Two missile flight profiles were described. The first was a high-altitude flight at 35,000 feet to the target area, with the missile descending to the target in a vertical dive. Arming and firing of the warhead would take place during this dive, and would be accomplished by the adaption-kit fuze. The missile was also to be capable of flight at low altitudes, and would be flown horizontally over the target at the desired burst height. Arming and firing would be accomplished by command signals sent over the missile guidance system.

(b)(3)

The adaption kit would include the fuzing system and the supports for the warhead and fuzing system in the missile. The fuzing system would have several new features. These included an acceleration-sensitive switch in place of a lanyard-operated switch as in previous designs, thereby eliminating the requirement for pullout wires. A safe-separation timer would provide two preset time intervals of 2 and 10 minutes, either of which could be selected just prior to launch. This option selection, previously accomplished by arming plugs, would be by selector

switch located on the launch panel. The system would be designed for a long-term ready-weapon capability, possibly 18 months under semicontrolled environmental conditions.[65]

By early 1956 the fuzing system was taking shape. The acceleration-sensitive switch would prevent inadvertent charging of the X-unit during storage and while the weapon was being readied for use.[66] This switch contained two sets of air pistons, operated by the launch acceleration, which would close a set of contacts when the warhead was subjected to a 4 g-second impulse. The contacts were spring-loaded, so that a force less than 1-1/2 g's would not close the contacts.

The safe-separation timer contained two sets of motor-driven gear and cam assemblies which closed electrical switches at the end of the timing intervals. One pair of switches closed at the end of 2 minutes, and the other at the end of 10 minutes. Timer action was started by missile-launch action.

The high-voltage thermal batteries for charging the X-unit were isolated by a squib-operated arm switch. During the safe-separation interval, power was kept from the warhead arming and firing circuits by the acceleration switch and the safe-separation timer.

(b)(3)

which controlled the pressure altitude at which the switches would close. An odometer, built into the knob, allowed the firing altitude to be read directly. Another set of four switches, wired into an arming network, was factory-adjusted to close at a specified altitude above the firing network. This furnished close arming, regardless of fuze setting.[67]

For the ground-burst option, the arming baroswitch closed at the arming altitude, with the firing baroswitch being disconnected from the circuit. The X-unit trigger circuit received a firing signal from the impact crystal network in the missile nose.

Sandia notified the Bureau of Aeronautics October 31, 1956, that the XW-27/REGULUS I flight tests, which were launched from Pt. Mugu, California, and impacted in the water at Salton Sea Test Base, had been highly successful. The Sandia-designed items were ready for certification, and the flight-test program would be completed with the seventh flight.[69,70]

The design release of the W-27/REGULUS I program was issued March 27, 1957.[71] This included the adaption kit and all test and handling equipment, with the exception of one item that was released in late April 1957.[72]

The Military Liaison Committee notified the Atomic Energy Commission July 3, 1957, that the Navy's operational-availability-date objective for the XW-27/REGULUS I adaption kit was October 1957, which matched the availability date of the warhead. However, production of the adaption kit had lagged the warhead time scales, and since kit hardware would not be available until February 1958, the warhead would be delayed until this date.[73] The warhead date was then slipped several months.[74]

Report SC4165(TR), Final Engineering Evaluation of the Mk 27 Mod 0 REGULUS I Warhead Application, was presented by Sandia to the April 23, 1958 meeting of the Special Weapons Development Board. The Board accepted the report for forwarding to the Division of Military Application.[75,76]

In the meantime, some work had been done on the REGULUS II application. Santa Fe Operations Office placed this program in full development January 18, 1956, as the first tactical REGULUS II missile was to be available by September 1957.[77] A proposed scope of work for the flight-test program was originated by Sandia, including 11 flights from Edwards Air Force Base, California.[78] However, the program was subsequently canceled.

RASCAL Warhead Application

The RASCAL was an air-to-surface, rocket-powered, supersonic missile with a range of about 90 nautical miles. The missile was 4 feet in diameter and 32 feet long, with one set of four fins near the nose and another set at the tail. The missile was designed and built by the Bell Aircraft Company for the Air Force. Its name was formed from the term RAdar SCAnning Link.

The missile was considered for XW-27 application in mid-1955. Some concern was created by the limitation imposed by the usable length of the warhead compartment in the missile, which was 77 inches. The location of the missile's air scoop was changed, along with modifications to the warhead support structure, adaption-kit components, and the main missile power supply, to avoid nuclear mass discontinuity problems.[14]

Enough progress had been made along these lines so that Sandia suggested to the Air Force Special Weapons Center November 30, 1955, that the XW-5-X1 Warhead could be canceled for application to the RASCAL, leaving the XW-27 as the sole warhead requirement.[79] This proposal was accepted, and early flight tests were made in the fall of 1956. An application design release was issued in January 1957, with the complete engineering release being made January 22, 1958.[80]

Report SC4164(TR), Final Engineering Evaluation of the Mk 27 Mod 0 GAM-63A (RASCAL) Warhead Application, was presented to the April 23, 1958 meeting of the Special Weapons Development Board.

(b)(1), (b)(3)

The Board accepted the report for forwarding to the Division of Military Application.[75,81]

a streamlined fighter plane with a maximum diameter of slightly over 4 feet, length of 39 feet, and swept-back wings. It was launched by a single, solid-propellant rocket, which accelerated the missile until the turbojet engine could attain sufficient thrust to sustain flight.

(b)(1), (b)(3)

The XW-27/MATADOR project was canceled in November 1956.[88]

SHAPE 96 Application

(b)(3)

Santa Fe Operations Office authorized full development work on the XW-27/F-101 project May 24, 1955.[89]

Design study indicated, however, that the Shape would require major modification to support the warhead and, since difficulties were being encountered with Shape 96, the project was canceled in March 1956.[90]

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Glossary of Mk 27 Terms

Adaption Kit -- Those items peculiar to the warhead installation less the warhead; namely, the arming and fuzing system, power supply, and all hardware, adapters and the like, required by a particular installation.

Air Force Special Weapons Center -- That element of the Air Force Systems Command having to do with compatibility testing of nuclear devices with aircraft. Located at Kirtland Air Force Base, Albuquerque, New Mexico.

Albuquerque Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with the operations of Sandia Corporation.

Arming -- The act of arming a weapon, that is, preparing it for firing.

Assistant Secretary of Defense -- Created by Department of Defense Directive, June 30, 1953, as part of DOD reorganization. Handles research and development activities of the DOD.

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Department of Defense -- The Armed Forces, i.e., the Army, Navy and Air Force.

Design Review and Acceptance Group -- A Military committee established to review the design of a specific weapon.

Detonators -- Devices containing bridge wires which, when subjected to an electrical current, burn rapidly and act as a match to apply a flame to various points on the outer surface of the high-explosive sphere.

Deuterium -- The hydrogen isotope of mass number 2.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

Dump -- The point in its trajectory at which a guided missile "dumps" or turns toward the target.

(b)(1), (b)(3)

Field Command -- The local office of the Armed Forces Special Weapons Project located on Sandia Base, Albuquerque, New Mexico.

Firing System -- The electrical system of the weapon that produces and applies a high-voltage current to the detonators.

Fissile Material -- Material capable of being fissioned.

Fuzing System -- The system that

g -- Force equal to one unit gravity.

Gas Boosting -- The technique of increasing the yield of a nuclear device by introducing deuterium-tritium gas into the implosion process to increase the fission activity.

Ground Burst -- Detonation at or very close to the surface of the bomb or target.

High Explosive Sphere -- The ball of high explosive that surrounds the nuclear primary and produces the implosion effect when detonated.

(b)(1), (b)(3)

JATO -- Named for Jet-Assisted Take-Off. A jet device initially designed to assist heavily loaded aircraft to take off from short runways. Used as a boosting device in missile launching.

Joint Chiefs of Staff -- An Army-Navy-Air Force group to determine policy and to develop joint strategic objectives of the Armed Forces.

Kilogram -- A metric weight approximating 2.2 pounds.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Kilovolt -- 1000 volts.

(b)(1), (b)(3)

Megaton -- A measure of yield of a large weapon. One megaton is the equivalent of 1,000,000 tons of high explosive.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established to advise and consult with the AEC on all matters relating to military applications of atomic energy.

Nautical Mile -- A naval measurement of length. One nautical mile is equivalent to 6076.1033 feet, or the length of 1 minute of arc (1/21,600) of a great circle of the earth.

Neutron -- An uncharged particle of slightly greater mass than the proton.

(b)(1), (b)(3)

(b)(3)

Teapot -- A less-than-full-scale test series held at the Nevada Test Site. Series of 14 tests, starting February 18 and ending May 15, 1955.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

Thyratron -- A grid-controlled electron tube.

Transonic -- A speed approximating that of Mach 1.0, the speed of sound; or 738 miles per hour at sea level.

Tritium -- The hydrogen isotope of mass number 3.

Two-Stage -- Combination of fission and fusion action in a weapon.

TX-Theta Committee -- A committee established to guide the development of thermonuclear weapons.

University of California Radiation Laboratory -- A nuclear design organization located at Livermore, California.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

Warhead -- As used in this history, a weapon carried to the target by missile.

X-Unit -- ~~A high-voltage transformer.~~ A device used to provide high voltage to the weapon detonators.

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January, 1968

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AEC ATOMIC WEAPON DATA
~~Sigma 3~~
SCORE
Changed to Sigma V per
Authority of Notice 3434 RA(137)
6/27/68. File No. 3589 7/2/68
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HISTORY OF THE MK 28 WEAPON

SC-M-67-665

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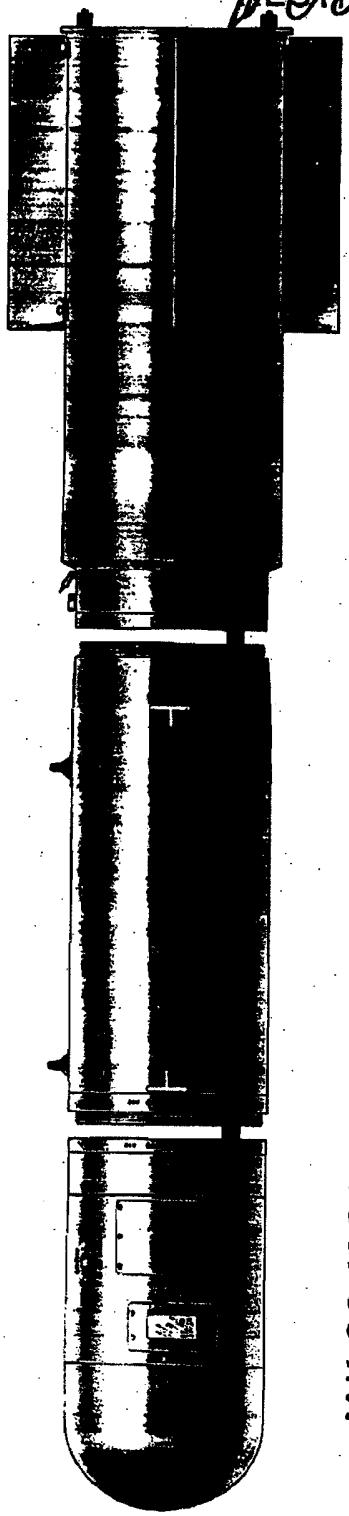
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MK 28 MOD 3 F MK 28 MOD 2 W MK 28 MOD 0 FISC

(b)(1), (b)(3)

MK 28 FI BOMB

Mk 28 FI Bomb - External View

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190
484
U.S. AIR FORCE

Timetable of Mk 28 Events

Mk 28 EX and IN Bombs

2/5/54

8/5/54 (b)(3)

11/4/54

11/7/54 TX-Theta Committee proposes design of XW-27 and XW-28.

3/24/55

(b)(3)

Spring 1955 (b)(1), (b)(3) Boosting techniques tested.

5/27/55 Sandia outlines design of a proposed TX-28 Bomb to the Division of Military Application.

6/29/55

(b)(3)

10/26/55 Proposed ordnance characteristics of TX-28 presented to Special Weapons Development Board.

(b)(1), (b)(3)

6/57 Mk 28 EX Mod 0 and Mk 28 IN Mod 0 Bombs design released.

8/21/57 Status at design release reported to Special Weapons Development Board.

8/58 Early production of Mk 28 EX and IN Bombs.

3/59 Final evaluation of Mk 28 EX and IN Bombs released.

Mk 28 RE Bomb

8/5/55	Possibility of creating a ruggedized Mk 28 Bomb discussed by TX-Theta Committee.
10/26/55	Test results of retardation devices presented to meeting of Special Weapons Development Board.
4/56	Proposal for retarded trajectory version of Mk 28 Bomb presented to Tableleg Committee.
8/3/56	Air Force Special Weapons Center advocates work on drogue parachute-retarded Mk 28 Bomb.
1/17/57	Division of Military Application released production authorization for drogue-retarded Mk 28.
4/58	Mk 28 RE Bomb design released.
8/20/58	Status-at-design-release report presented to meeting of Special Weapons Development Board.
3/59	Early production of Mk 28 RE Bomb achieved.
11/59	Final evaluation of report of Mk 28 Mod 1 Bomb released.

Mk 28 RI Bomb

3/58	Strategic Air Command notes that high-altitude target approaches will be abandoned in favor of low-altitude approaches.
4/17/58	Assistant Secretary of Defense requests United States Atomic Energy Commission to develop a maximum-drogued Mk 28 Bomb.
4/59	TX-28-X2 design released.
10/21/59	Report on status at design release presented to meeting of Special Weapons Development Board.
6/60	Mk 28 RI production achieved.

Mk 28 FI Bomb

6/30/59	Sandia proposes design of a full-fuzing-option Mk 28 Bomb, with laydown capability.
8/18/60	Operational requirement for TX-28-X3 released.

10/12/61	Proposed ordnance characteristics of TX-28-X3 accepted by Field Command.
7/62	Early production of Mk 28 FI achieved.
5/63	Final development report of Mk 28 FI Bomb released.

Mk 28 Warhead

6/57	Mk 28 Mod 0 Warhead design released.
8/58	Early production of Mk 28 Mod 0 Warhead achieved.
5/60	Early production of Mk 28 Mod 1 Warhead achieved.
1/62	Early production of Mk 28 Mod 2 Warhead achieved.
12/62	Early production of Mk 28 Mod 3 Warhead achieved.
7/63	Early production of Mk 28 Mod 4 Warhead achieved.

Mk 28/MACE Warhead Installation

1/18/56	Production authorization released for Mk 28/MATADOR. Missile later redesignated MACE.
3/14/56	Military characteristics for Mk 28/MACE approved by Military Liaison Committee.
6/59	Mk 28 Mod 0 Warhead released for use in the MACE missile.
8/62	Final evaluation report of MACE Warhead Application released.

Mk 28/HOUND DOG Warhead Installation

1/58	Feasibility study of warhead installation for HOUND DOG missile requested.
5/16/58	Assistant Secretary of Defense selects XW-28 Warhead for installation in HOUND DOG missile.
5/28/60	Initial authorization for restricted use of Mk 28/HOUND DOG issued.
12/61	General release of Mk 28/HOUND DOG authorized.
3/62	Final evaluation of Mk 28 Mod 1 Warhead in HOUND DOG missile released.

Details of the TX-28 design then became firm. The weapon center section would be a partially contoured cylindrical case, 20 inches in diameter and 49 inches long, and capped at each end with a hemisphere.

(b)(1), (b)(3)

One fin could be folded, to provide ground and aircraft carriage clearance. The fin control mechanism would be powered by explosive squibs, actuated at bomb release from the carrying aircraft. The feasibility of the 3-hook suspension was felt to be doubtful, in view of possible warhead requirements, and this design was dropped.[18]

The design of the TX-28 Prime fuze was also proceeding rapidly. One-shot, explosively actuated switches would control such actions as preheat current switching, timer output selection, high-voltage thermal-battery arming, ground- or air-burst selection, contact-fuze arming, timer-motor starting, trajectory-arm-switch pressure-port sealing, gas-boost initiation, and even thermal-battery monitoring. These switches were small, light, resistant to shock, and could be used extensively.[19]

Operational safety would be increased by the installation of a switch which would close after experiencing the normal trajectory of a free-fall bomb. This switch was a dual-chamber baroswitch. One chamber was sealed when the bomb was released from the aircraft, and the second measured the pressure increase as the bomb fell toward its target.

(b)(1), (b)(3)

Choice of air burst or contact option would be made before takeoff, and the operations required of the pilot prior to release of the weapon were reduced to 3, as compared to about 15 required for other tactical fuzes. Basic design emphasis was placed on simplification, miniaturization and operational safety.

The length of the bomb was 170 inches, thus resulting in a fineness ratio of 8.5, and the weight was estimated to be 1700 pounds. The bomb was divided into three parts: Nose (containing fuze), center section (containing primary and secondary), and tail. The weapon could be shortened for internal carriage

interval timer, 28 volts was applied to the squib transformers of the high-voltage thermal-battery pack. This activated the batteries and initiated charging of the X-unit capacitor bank. The firing circuits of the radar sets were also armed at this time.

When the bomb fell to an altitude above the target equal to the range setting in the radar system, a firing relay in the radars connected 28 volts to the weapon firing circuit and triggered the spark gap. The 2500-volt output of the X-unit then discharged through the gap, firing the weapon detonators.

If the radar system failed, ground impact operated the contact crystals unless contact preclusion had been selected before aircraft takeoff. Operation of the contact crystals produced a voltage which triggered the thyratron in the weapon trigger circuit. A capacitor then discharged through a pulse transformer in the weapon firing circuit and triggered the spark gap.

Contact option was made by selecting the Ground option on the aircraft monitor and control system. This action operated the electrical safing switches in the weapon. At bomb release, thermal batteries were activated, interval timer started, pressure ports of the fixed differential pressure switch sealed, fin extending mechanism actuated (for externally carried bombs only), and the contact option switch which disconnected the radar fire line was operated. The pullout switch closed, applying the 28-volt output of the thermal batteries to the fuzing system.

(b)(1), (b)(3)

At the end of the safe-separation time preset on the interval timer, a switch closed to operate the contact arm switch and start charging the X-unit. At ground impact, the crystal net produced a voltage which triggered a thyratron and subsequently the spark gap. The X-unit output then discharged through the gap, firing the weapon detonators.[31]

use of shock-mitigating materials. It was felt possible to design a bomb to withstand laydown impact shocks of 200 to 300 g's.[33]

Design progress was discussed in the October 26, 1955 meeting of the Special Weapons Development Board. Sandia stated that both parachutes and rotochutes had been tested. Existing parachute designs were not able to absorb the shock created by a bomb released at high speeds, and a stronger parachute was being designed. Rotochutes could not properly handle the bomb weight. Retrorockets had been considered, but these imposed operational restrictions.

Sandia had recorded promising shock-cushioning tests of honeycomb material in drops from 14- and 80-foot towers, and was erecting a 300-foot tower, which would produce vertical impact velocities of about 135 feet per second, about that of a parachute-retarded bomb. Devices to be tested would be guided by a slanting cable which would allow application of side forces, such as those caused by wind effects or tumbling of the weapon after target impact.[22]

Early in 1956, Sandia analyzed the delivery characteristics of several low-level, retarded-delivery systems. The study concluded that a retarded trajectory version of a nonimpact-resistant TX-28 type weapon was desirable, and that this device could be produced well before the true laydown weapons then under development. The study results were subsequently presented to the Tableleg Committee (investigating the laydown design) in April 1956 as an interim method of achieving many of the laydown weapon objectives about 2 years in advance of the true laydown weapon.[34]

Results of the study were incorporated in Report SC3860(TR), Design Study of *a Drogue-Retarded TX-28 Weapon Family. The study proposed finless external* and internal retarded versions of the TX-28 free-fall bombs, but without the capability of inflight selection of retarded or free-fall delivery.[34]

After presentation to the Air Force of proposals for retardation of TX-28 weapons, the Air Force requested the capability of inflight selection of retarded or free-fall delivery. Preliminary investigation showed that this could be accomplished by using a small pilot parachute for stabilization in

If the radar system failed, impact with the ground operated the contact crystals unless contact preclusion had been selected before takeoff. Operation of these crystals produced a voltage that triggered a thyratron, discharging a capacitor through the spark gap, and firing the X-unit and detonators.

In the contact option, preflight setting of the option plug to the contact backup position was made. The contact option was then chosen in flight by turning to the Ground position on the aircraft monitor and control. At bomb release, arming was accomplished in the same manner as for the air-burst option, and aircraft power through the pulse plug fired an option switch which disconnected the radar fire lines from the weapon firing circuit. At the end of safe-separation time, a squib switch in the trigger circuit was actuated, closing the line between a thyratron tube and the gap firing transformer, thus arming the contact system. At surface impact, the crystal network produced a voltage that detonated the bomb.

Contact bursts could be precluded by preflight setting of the option plug to the contact-preclude position. The arming and firing sequence was the same as for the air-burst option with contact backup, except that the contact system was never armed.[35]

Report SC4150(TR), Description and Status at Complete Design Release of the TX-28-X1 Bomb, was presented to the August 20, 1958 meeting of the Special Weapons Development Board.[46] The Mk 28 EX Mod 1 was 160 inches long, weighed 2020 pounds, and provided external carriage and free-fall delivery. The Mk 28 IN Mod 1 was 96.4 inches long, weighed 1940 pounds, and provided internal carriage and free-fall delivery. The Mk 28 RE Mod 1 was 166 inches long, weighed 2140 pounds, and provided retarded delivery.

(b)(1), (b)(3)

The radar was capable of reliable operation at all weapon attitude angles up to and including 60 degrees from the vertical. For larger angles, the system reliability was lowered. There were two fuzing limitations. A 10-second timer setting was the minimum available for safe separation, and

impractical, and the system was changed to include a motor-operated arm/safe switch, which completed the circuit between the pulse generator and the low-voltage thermal battery. This change permitted the bomb to be dropped in a safe condition without initiating the power supplies.

The TX-28-X2 was design released in April 1959 and Report SC4253(TR), Status at Complete Design Release of the TX-28-X2 Bomb, was presented to the October 21, 1959 meeting of the Special Weapons Development Board.[53] The forward section of the bomb was 20 inches in diameter and the tail section was 22 inches in diameter. The bomb was 132 inches long, weighed 2265 pounds and could be internally carried in B-47 and B-52 bombers.

(b)(3)

The Mk 28 Retarded Internal Bomb achieved production in June 1960. The design consisted of the Mk 28 Mod 1 Warhead, Mk 28 Mod 2 Fuze, and Mk 28 Mod 0 Retarded Internal Shape Components.

Before loading the weapon in the delivery aircraft, the safe condition of the system was checked with a built-in continuity monitor and a safe-separation timer was set. After loading, the aircraft monitor and control power was turned on with the option select switch in Safe position. This released a solenoid interlock on the Ready/Safe switch, which was then turned to Ready.

In flight, and preferably after entering enemy territory, ground burst was selected on the aircraft control. When this was done, two arming/safing switches operated to the Arm Position. One of these switches connected the pulse-generator output to the initiating circuits of the low-voltage thermal-battery pack, and the other connected the high-voltage battery to the X-unit capacitor bank. If air burst was inadvertently selected, the system would function in the same way and automatically selected ground burst.

At bomb release, pullout rods actuated pulse generators. Output pulses from these generators initiated low-voltage thermal batteries and started deployment

timers. As the bomb entered the airstream, differential pressure across the aerodynamic fences caused a pressure switch to close, connecting the 1-second contacts in the deployment timers to the activation circuits of the detonators, safe-separation timer, and switch pack. At the end of 1 second, timer contacts closed, connecting the 12-volt sections of the low-voltage thermal batteries to the components noted.

The detonators fired and initiated a length of mild detonating fuse which blew off the rear cover plate. As the cover plate fell away, it deployed the pilot parachute, which in turn deployed the first-stage chute. Explosive motors in the safe-separation timer fired and unlatched the starting mechanism, which allowed the timer to begin timing. The switch pack operated and connected the 28-volt sections of the low-voltage batteries to the safe-separation timer contacts, trigger-circuit option switch, and explosive motors in the reservoir and valve assembly.

(b)(3)

The actuators fired, causing the bolt to fracture. The lug release ring separated from the lug mounting plate. The lugs pivoted, releasing risers of the first-stage parachute. As the first-stage chute fell away, it deployed the second-stage chute.

At the end of safe-separation time, contacts of the safe-separation timer closed and connected the 28-volt output of the low-voltage batteries to the primaries of the high-voltage-battery actuating transformers. The high-voltage thermal batteries activated and charged the X-unit capacitor bank.

Since existing radars would require more space than could be provided, and a smaller unit, being designed, would not be immediately available, a timer fuze was proposed. This was rejected, after study, as it involved possible errors in release altitude and variations in the time of fall. A baroswitch with a fixed burst altitude was then considered, and felt to be acceptable.

A remotely settable baroswitch was required, in order to permit the Strategic Air Command to control the fixed setting at depot level with available equipment. To eliminate the need for preflight selection of retarded or free-fall delivery mode, a system was proposed in which the release altitude was sensed and used to select the mode automatically. If the release was made at high altitudes, the weapon would drop free fall; with a low-altitude release, a retardation system would be used. The two altitude ranges were separated by a region in which weapon releases were not anticipated. For free-fall drops, the aircraft would be at or near its maximum altitude and, for retarded drops, the altitude would be only a few thousand feet above sea level. Several available switches could be used. The firing signal would be supplied by a timer in the laydown option and by contact crystals for surface detonation.

An operational requirement for the TX-28-X3 was issued by the Deputy Director for Research and Engineering August 18, 1960, and early production requested in February 1962. The design would be capable of being released 500 feet above the target, be carried internally in the B-47 and B-52 aircraft, and have a full-fuzing option.[58]

The bomb nose was provided with 8 inches of crushable honeycomb to absorb laydown shocks. A fourth parachute was added to the Mk 28 Retarded Internal Bomb design to provide free-fall stabilization and reduce baro sensing errors, and the design was released October 1961.

Report SC4534(WD), Proposed Ordnance Characteristics of the TX-28-X3 Bomb, was accepted by Field Command October 12, 1961. The Mk 28 FI Bomb consisted of a Mk 28 Mod 2 Warhead, Mk 28 Mod 3 Fuze, and Mk 28 Mod 0 Full-Fuzing

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January, 1968

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AEC ATOMIC WEAPON DATA
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HISTORY OF THE MK 28 WEAPON

SC-M-67-665

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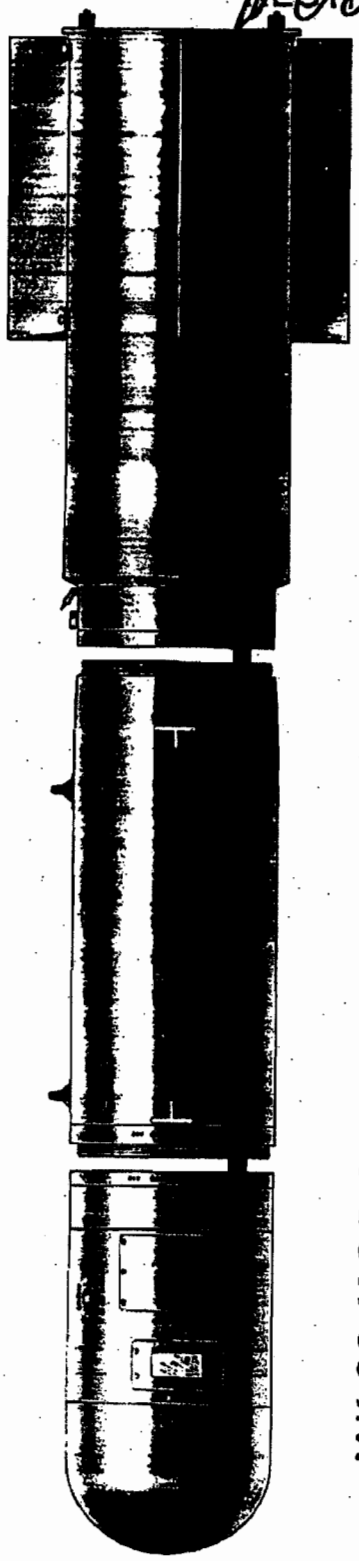
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MK 28 MOD 3 F MK 28 MOD 2 W MK 28 MOD 0 FISC

(b)(1), (b)(3)

MK 28 FI BOMB

Mk 28 FI Bomb - External View

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Timetable of Mk 28 Events

Mk 28 EX and IN Bombs

2/5/54

8/5/54 (b)(3)

11/4/54

11/7/54 TX-Theta Committee proposes design of XW-27 and XW-28.

3/24/55

(b)(3)

Spring 1955 (b)(1), (b)(3) Boosting techniques tested.

5/27/55 Sandia outlines design of a proposed TX-28 Bomb to the Division of Military Application.

6/29/55

(b)(3)

10/26/55 Proposed ordnance characteristics of TX-28 presented to Special Weapons Development Board.

(b)(1), (b)(3)

6/57 Mk 28 EX Mod 0 and Mk 28 IN Mod 0 Bombs design released.

8/21/57 Status at design release reported to Special Weapons Development Board.

8/58 Early production of Mk 28 EX and IN Bombs.

3/59 Final evaluation of Mk 28 EX and IN Bombs released.

Mk 28 RE Bomb

8/5/55	Possibility of creating a ruggedized Mk 28 Bomb discussed by TX-Theta Committee.
10/26/55	Test results of retardation devices presented to meeting of Special Weapons Development Board.
4/56	Proposal for retarded trajectory version of Mk 28 Bomb presented to Tableleg Committee.
8/3/56	Air Force Special Weapons Center advocates work on drogue parachute-retarded Mk 28 Bomb.
1/17/57	Division of Military Application released production authorization for drogue-retarded Mk 28.
4/58	Mk 28 RE Bomb design released.
8/20/58	Status-at-design-release report presented to meeting of Special Weapons Development Board.
3/59	Early production of Mk 28 RE Bomb achieved.
11/59	Final evaluation of report of Mk 28 Mod 1 Bomb released.

Mk 28 RI Bomb

3/58	Strategic Air Command notes that high-altitude target approaches will be abandoned in favor of low-altitude approaches.
4/17/58	Assistant Secretary of Defense requests United States Atomic Energy Commission to develop a maximum-drogued Mk 28 Bomb.
4/59	TX-28-X2 design released.
10/21/59	Report on status at design release presented to meeting of Special Weapons Development Board.
6/60	Mk 28 RI production achieved.

Mk 28 FI Bomb

6/30/59	Sandia proposes design of a full-fuzing-option Mk 28 Bomb, with laydown capability.
8/18/60	Operational requirement for TX-28-X3 released.

10/12/61	Proposed ordnance characteristics of TX-28-X3 accepted by Field Command.
7/62	Early production of Mk 28 FI achieved.
5/63	Final development report of Mk 28 FI Bomb released.

Mk 28 Warhead

6/57	Mk 28 Mod 0 Warhead design released.
8/58	Early production of Mk 28 Mod 0 Warhead achieved.
5/60	Early production of Mk 28 Mod 1 Warhead achieved.
1/62	Early production of Mk 28 Mod 2 Warhead achieved.
12/62	Early production of Mk 28 Mod 3 Warhead achieved.
7/63	Early production of Mk 28 Mod 4 Warhead achieved.

Mk 28/MACE Warhead Installation

1/18/56	Production authorization released for Mk 28/MATADOR. Missile later redesignated MACE.
3/14/56	Military characteristics for Mk 28/MACE approved by Military Liaison Committee.
6/59	Mk 28 Mod 0 Warhead released for use in the MACE missile.
8/62	Final evaluation report of MACE Warhead Application released.

Mk 28/HOUND DOG Warhead Installation

1/58	Feasibility study of warhead installation for HOUND DOG missile requested.
5/16/58	Assistant Secretary of Defense selects XW-28 Warhead for installation in HOUND DOG missile.
5/28/60	Initial authorization for restricted use of Mk 28/HOUND DOG issued.
12/61	General release of Mk 28/HOUND DOG authorized.
3/62	Final evaluation of Mk 28 Mod 1 Warhead in HOUND DOG missile released.

The missile warhead weight would be a minimum and not exceed 2800 pounds. The warhead would be compatible with the Air Force MATADOR, RASCAL, SNARK and NAVAHO; the Navy REGULUS and TRITON; and the Army REDSTONE. Manually and electrically operated arming and safing components would be incorporated, as well as a device to monitor the safe or armed condition of the warhead.

(b)(1), (b)(3)

The TX-Theta Committee, meeting September 17, 1954, reported that the weight and diameter of externally carried bombs had a significant effect on the range and speed of carrying aircraft.

(b)(3)

The TX-Theta Committee again met November 5, 1954.

(b)(1), (b)(3)

The TX-Theta Committee wrote to Santa Fe Operations Office, November 17, 1954, proposing that two different weapons be built, a large-diameter XW-27 Warhead compatible with missile carriers and a smaller diameter TX-28 Bomb to be externally and internally carried on high performance fighter bombers.

(b)(1), (b)(3)

It was hoped that suitable weapon designs could be released by early 1957, with production occurring in the mid-part of that year.[5]

Sandia discussed the design of the TX-28 in the December 1, 1954 meeting of the Special Weapons Development Board. The maximum length of the bomb was felt to be 250 inches, although shorter lengths suitable for internal carriage

(b)(1), (b)(3)

It was hoped that a bomb considerably smaller in diameter and weighing less than 2800 pounds could be developed and, if necessary, some reduction in yield would be acceptable. The Military Liaison Committee requested that a diameter of about 25 inches be considered, and this study was assigned high priority.[8]

(b)(1), (b)(3)

(b)(1), (b)(3)

Also, due to radioactive decay, the amount of tritium in the gas decreased steadily and had to be periodically replaced. This replacement could be most conveniently done if the boosting gas was in a replaceable reservoir.

(b)(3)

By April 1955, Sandia was designing the TX-28 fuze. Barometric fuzing had been considered, but rejected due to the wide variety of delivery systems and consequent variation in delivery velocities. This variation made it difficult to develop a satisfactory pressure-sensing system, and the use of different field settings for each mission would have negated a ready-weapon concept. A timer was considered, and would have allowed a slightly better minimum release angle in LABS (Low-Altitude Bombing System) missions and a

Details of the TX-28 design then became firm. The weapon center section would be a partially contoured cylindrical case, 20 inches in diameter and 49 inches long, and capped at each end with a hemisphere.

(b)(1), (b)(3)

One fin could be folded, to provide ground and aircraft carriage clearance. The fin control mechanism would be powered by explosive squibs, actuated at bomb release from the carrying aircraft. The feasibility of the 3-hook suspension was felt to be doubtful, in view of possible warhead requirements, and this design was dropped.[18]

The design of the TX-28 Prime fuze was also proceeding rapidly. One-shot, explosively actuated switches would control such actions as preheat current switching, timer output selection, high-voltage thermal-battery arming, ground- or air-burst selection, contact-fuze arming, timer-motor starting, trajectory-arm-switch pressure-port sealing, gas-boost initiation, and even thermal-battery monitoring. These switches were small, light, resistant to shock, and could be used extensively.[19]

Operational safety would be increased by the installation of a switch which would close after experiencing the normal trajectory of a free-fall bomb. This switch was a dual-chamber baroswitch. One chamber was sealed when the bomb was released from the aircraft, and the second measured the pressure increase as the bomb fell toward its target.

(b)(1), (b)(3)

Choice of air burst or contact option would be made before takeoff, and the operations required of the pilot prior to release of the weapon were reduced to 3, as compared to about 15 required for other tactical fuzes. Basic design emphasis was placed on simplification, miniaturization and operational safety.

The length of the bomb was 170 inches, thus resulting in a fineness ratio of 8.5, and the weight was estimated to be 1700 pounds. The bomb was divided into three parts: Nose (containing fuze), center section (containing primary and secondary), and tail. The weapon could be shortened for internal carriage

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(b)(3)

Report SC3691(TR), Proposed Ordnance Characteristics of the TX-28 Atomic Weapon, was presented to the October 26, 1955 meeting of the Special Weapons Development Board.[22] This report noted that the tail could be rotated in increments, thus allowing the fin to fold either up or down. A fuze access panel was provided, to allow access to the high-voltage thermal cells.

A pulse pullout plug fired squib switches when the bomb was released from the carrying aircraft. The case of this plug failed at a break line, and the two sections of the plug separated. The safety ground was broken during the motion of the plug and a pulse of 28-volt aircraft power applied to the squib lines. The safe-separation timer was dual-channeled for reliability. Both long and short times were available, and both times could be set in each channel.[23]

(b)(1), (b)(3)

Santa Fe Operations Office accepted these yield designations, but requested

identify the internal-carriage version.[27] Sandia noted that omission of yield or configuration designation would mean broad applicability to all yields or configurations.[28]

(b)(1), (b)(3)

The Mk 28 EX Mod 0 and Mk 28 IN Mod 0 were design released June 1957, and early production achieved in August 1958. Sandia presented Report SC4092(TR),

interval timer, 28 volts was applied to the squib transformers of the high-voltage thermal-battery pack. This activated the batteries and initiated charging of the X-unit capacitor bank. The firing circuits of the radar sets were also armed at this time.

When the bomb fell to an altitude above the target equal to the range setting in the radar system, a firing relay in the radars connected 28 volts to the weapon firing circuit and triggered the spark gap. The 2500-volt output of the X-unit then discharged through the gap, firing the weapon detonators.

If the radar system failed, ground impact operated the contact crystals unless contact preclusion had been selected before aircraft takeoff. Operation of the contact crystals produced a voltage which triggered the thyratron in the weapon trigger circuit. A capacitor then discharged through a pulse transformer in the weapon firing circuit and triggered the spark gap.

Contact option was made by selecting the Ground option on the aircraft monitor and control system. This action operated the electrical safing switches in the weapon. At bomb release, thermal batteries were activated, interval timer started, pressure ports of the fixed differential pressure switch sealed, fin extending mechanism actuated (for externally carried bombs only), and the contact option switch which disconnected the radar fire line was operated. The pullout switch closed, applying the 28-volt output of the thermal batteries to the fuzing system.

(b)(1). (b)(3)

At the end of the safe-separation time preset on the interval timer, a switch closed to operate the contact arm switch and start charging the X-unit. At ground impact, the crystal net produced a voltage which triggered a thyratron and subsequently the spark gap. The X-unit output then discharged through the gap, firing the weapon detonators.[31]

use of shock-mitigating materials. It was felt possible to design a bomb to withstand laydown impact shocks of 200 to 300 g's.[33]

Design progress was discussed in the October 26, 1955 meeting of the Special Weapons Development Board. Sandia stated that both parachutes and rotochutes had been tested. Existing parachute designs were not able to absorb the shock created by a bomb released at high speeds, and a stronger parachute was being designed. Rotochutes could not properly handle the bomb weight. Retrorockets had been considered, but these imposed operational restrictions.

Sandia had recorded promising shock-cushioning tests of honeycomb material in drops from 14- and 80-foot towers, and was erecting a 300-foot tower, which would produce vertical impact velocities of about 135 feet per second, about that of a parachute-retarded bomb. Devices to be tested would be guided by a slanting cable which would allow application of side forces, such as those caused by wind effects or tumbling of the weapon after target impact.[22]

Early in 1956, Sandia analyzed the delivery characteristics of several low-level, retarded-delivery systems. The study concluded that a retarded trajectory version of a nonimpact-resistant TX-28 type weapon was desirable, and that this device could be produced well before the true laydown weapons then under development. The study results were subsequently presented to the Tableleg Committee (investigating the laydown design) in April 1956 as an interim method of achieving many of the laydown weapon objectives about 2 years in advance of the true laydown weapon.[34]

Results of the study were incorporated in Report SC3860(TR), Design Study of a Drogue-Retarded TX-28 Weapon Family. The study proposed finless external and internal retarded versions of the TX-28 free-fall bombs, but without the capability of inflight selection of retarded or free-fall delivery.[34]

After presentation to the Air Force of proposals for retardation of TX-28 weapons, the Air Force requested the capability of inflight selection of retarded or free-fall delivery. Preliminary investigation showed that this could be accomplished by using a small pilot parachute for stabilization in

the free-fall mode and by using the pilot chute to deploy a large drogue parachute for the retarded mode. Selection of delivery option would be accomplished by minor modification of the aircraft monitor and control system.[35]

The Air Force Special Weapons Center wrote to Field Command August 3, 1956, advocating the drogue parachute program, as this would increase bomb-delivery accuracy. The existing bomb tail would not be large enough to hold the drogue parachute, and a new tail would have to be provided. This increase in size would aggravate ground and aircraft clearance problems, and might make it impossible to allow room for stabilizing fins. Thus, a decision to use this type of delivery might have to be made before final bomb assembly.[36]

The Division of Military Application was notified September 26, 1956 that a drogue-retarded TX-28 weapon family would not delay or compromise the rest of the project. The weapon system would be a little complex, due to the number of different units required to make the TX-28 a universal-use weapon. However, it was felt that production and stockpiling problems would not be too formidable.[37,38]

Production authorization for the drogue-retarded Mk 28 was issued January 17, 1957 by the Division of Military Application.[39] The design was named the TX-28-X1, and a stockpile date of June 1958 was requested.[40] The tail would incorporate two parachutes; a small, stabilizing chute for free-fall deliveries and a larger chute for retarded deliveries. When the large chute was used, the section containing the small chute would be jettisoned.[41]

The design would have the capability of inflight selection of retarded or free-fall option in a single, streamlined shape suitable for external carriage by the designated aircraft and for internal carriage by the A3D, and no changes to the aircraft monitor and control system would be required. No requirement was established for an internally carried retarded TX-28 as it was felt that this would unacceptably complicate weapon design, stockpiling and logistics.[42]

If the radar system failed, impact with the ground operated the contact crystals unless contact preclusion had been selected before takeoff. Operation of these crystals produced a voltage that triggered a thyratron, discharging a capacitor through the spark gap, and firing the X-unit and detonators.

In the contact option, preflight setting of the option plug to the contact backup position was made. The contact option was then chosen in flight by turning to the Ground position on the aircraft monitor and control. At bomb release, arming was accomplished in the same manner as for the air-burst option, and aircraft power through the pulse plug fired an option switch which disconnected the radar fire lines from the weapon firing circuit. At the end of safe-separation time, a squib switch in the trigger circuit was actuated, closing the line between a thyratron tube and the gap firing transformer, thus arming the contact system. At surface impact, the crystal network produced a voltage that detonated the bomb.

Contact bursts could be precluded by preflight setting of the option plug to the contact-preclude position. The arming and firing sequence was the same as for the air-burst option with contact backup, except that the contact system was never armed.[35]

Report SC4150(TR), Description and Status at Complete Design Release of the TX-28-X1 Bomb, was presented to the August 20, 1958 meeting of the Special Weapons Development Board.[46] The Mk 28 EX Mod 1 was 160 inches long, weighed 2020 pounds, and provided external carriage and free-fall delivery. The Mk 28 IN Mod 1 was 96.4 inches long, weighed 1940 pounds, and provided internal carriage and free-fall delivery. The Mk 28 RE Mod 1 was 166 inches long, weighed 2140 pounds, and provided retarded delivery.

(b)(1), (b)(3)

The radar was capable of reliable operation at all weapon attitude angles up to and including 60 degrees from the vertical. For larger angles, the system reliability was lowered. There were two fuzing limitations. A 10-second timer setting was the minimum available for safe separation, and

(b)(3)

Firing was then accomplished, either by radars ranging for air-burst or by impact fuzes at time of contact.[47]

Mk 28 Retarded Internal (RI) Bomb

In late March 1958, the Strategic Air Command noted that enemy defenses had increased to the point where all high-altitude target bombing approaches were being abandoned in favor of an "on-the-deck" approach. It was pointed out that no thermonuclear bomb currently available could be released at altitudes of 1500 feet or less, and it was requested that the Mk 28 be modified to allow it to be so released. The carrying aircraft would be the B-47, and some degradation in ballistic performance would be acceptable, if an immediate capability could be provided.[48]

Subsequently, April 17, 1958, the Assistant Secretary of Defense requested the Atomic Energy Commission to develop a maximum-drogued Mk 28 Bomb. This design would require a new afterbody, parachute and fuze, and would be supplied in the form of a conversion kit that could be applied to any stockpiled Mk 28. This TX-28-X2 design would have a 40-second down-time from a release altitude of 1500 feet. The weapon would be fuzed for contact burst only, and would be capable of being carried in the B-47, B-52 and possibly the B-66.[49]

Design work was immediately started.[50] Initial verbal requirements were for a "fail-safe" system in which the weapon would not arm and fire in the event of parachute failure. However, on the basis of informal guidance, a "fail-arm" system, which would arm and fire regardless of proper parachute operation, was considered and specified in early August 1958. No external power would be required, except for a prerelease arming signal. At release, a pulse of power from a generator would initiate fast-rise thermal batteries that would subsequently furnish all the bomb power requirements.[51]

The design required that the pullout cables be located in the bomb tail and the fuze in the bomb nose, and external fairings were installed to connect

these two sections and provide room for interconnecting cabling. The bomb was armed or safed by the aircraft monitor and control system, with high-voltage safing being accomplished by a motor-driven switch, and low-voltage safing by a manually operated control. A check of the safe or ready condition of the weapon could be made by a hand-cranked continuity tester whose output current was less than that required to fire any bomb component.

The initial approach to the design of the fail-arm fuze was to provide automatic selection of arming time compatible with proper parachute operation.

(b)(3)

Since the retarded time of fall was 50 seconds, the thermal batteries required comparatively long life. No existing battery was suitable, and work was started on a new design. As information on the deceleration signature of the parachute deployment system would not be available until late in the program, it was decided to provide an alternate system. In this design, closing of a trajectory arm switch fired an explosive device that locked-in the arming power. The closure of this device completed the circuit from the low-voltage thermal battery to the arming components, and thus a highly reliable design was needed. This was furnished by an existing switch activated by either of two squibs and having a fusible disc that would melt in a fire and disconnect the switch from the weapon system. The Military subsequently requested that the bomb system be designed to fail-safe, to assure safe-separation time for carrier aircraft, and a safe-separation timer was added.[52]

Initially, it had been planned to install removable safing pins in the pulse-generator pull rods, and the Air Force was to provide a manual system to remove these pins after the weapon was airborne. This was found to be

impractical, and the system was changed to include a motor-operated arm/safe switch, which completed the circuit between the pulse generator and the low-voltage thermal battery. This change permitted the bomb to be dropped in a safe condition without initiating the power supplies.

The TX-28-X2 was design released in April 1959 and Report SC4253(TR), Status at Complete Design Release of the TX-28-X2 Bomb, was presented to the October 21, 1959 meeting of the Special Weapons Development Board.[53] The forward section of the bomb was 20 inches in diameter and the tail section was 22 inches in diameter. The bomb was 132 inches long, weighed 2265 pounds and could be internally carried in B-47 and B-52 bombers.

(b)(3)

The Mk 28 Retarded Internal Bomb achieved production in June 1960. The design consisted of the Mk 28 Mod 1 Warhead, Mk 28 Mod 2 Fuze, and Mk 28 Mod 0 Retarded Internal Shape Components.

Before loading the weapon in the delivery aircraft, the safe condition of the system was checked with a built-in continuity monitor and a safe-separation timer was set. After loading, the aircraft monitor and control power was turned on with the option select switch in Safe position. This released a solenoid interlock on the Ready/Safe switch, which was then turned to Ready.

In flight, and preferably after entering enemy territory, ground burst was selected on the aircraft control. When this was done, two arming/safing switches operated to the Arm Position. One of these switches connected the pulse-generator output to the initiating circuits of the low-voltage thermal-battery pack, and the other connected the high-voltage battery to the X-unit capacitor bank. If air burst was inadvertently selected, the system would function in the same way and automatically selected ground burst.

At bomb release, pullout rods actuated pulse generators. Output pulses from these generators initiated low-voltage thermal batteries and started deployment

timers. As the bomb entered the airstream, differential pressure across the aerodynamic fences caused a pressure switch to close, connecting the 1-second contacts in the deployment timers to the activation circuits of the detonators, safe-separation timer, and switch pack. At the end of 1 second, timer contacts closed, connecting the 12-volt sections of the low-voltage thermal batteries to the components noted.

The detonators fired and initiated a length of mild detonating fuse which blew off the rear cover plate. As the cover plate fell away, it deployed the pilot parachute, which in turn deployed the first-stage chute. Explosive motors in the safe-separation timer fired and unlatched the starting mechanism, which allowed the timer to begin timing. The switch pack operated and connected the 28-volt sections of the low-voltage batteries to the safe-separation timer contacts, trigger-circuit option switch, and explosive motors in the reservoir and valve assembly.

(b)(3)

The actuators fired, causing the bolt to fracture. The lug release ring separated from the lug mounting plate. The lugs pivoted, releasing risers of the first-stage parachute. As the first-stage chute fell away, it deployed the second-stage chute.

At the end of safe-separation time, contacts of the safe-separation timer closed and connected the 28-volt output of the low-voltage batteries to the primaries of the high-voltage-battery actuating transformers. The high-voltage thermal batteries activated and charged the X-unit capacitor bank.

Since existing radars would require more space than could be provided, and a smaller unit, being designed, would not be immediately available, a timer fuze was proposed. This was rejected, after study, as it involved possible errors in release altitude and variations in the time of fall. A baroswitch with a fixed burst altitude was then considered, and felt to be acceptable.

A remotely settable baroswitch was required, in order to permit the Strategic Air Command to control the fixed setting at depot level with available equipment. To eliminate the need for preflight selection of retarded or free-fall delivery mode, a system was proposed in which the release altitude was sensed and used to select the mode automatically. If the release was made at high altitudes, the weapon would drop free fall; with a low-altitude release, a retardation system would be used. The two altitude ranges were separated by a region in which weapon releases were not anticipated. For free-fall drops, the aircraft would be at or near its maximum altitude and, for retarded drops, the altitude would be only a few thousand feet above sea level. Several available switches could be used. The firing signal would be supplied by a timer in the laydown option and by contact crystals for surface detonation.

An operational requirement for the TX-28-X3 was issued by the Deputy Director for Research and Engineering August 18, 1960, and early production requested in February 1962. The design would be capable of being released 500 feet above the target, be carried internally in the B-47 and B-52 aircraft, and have a full-fuzing option.[58]

The bomb nose was provided with 8 inches of crushable honeycomb to absorb laydown shocks. A fourth parachute was added to the Mk 28 Retarded Internal Bomb design to provide free-fall stabilization and reduce baro sensing errors, and the design was released October 1961.

Report SC4534(WD), Proposed Ordnance Characteristics of the TX-28-X3 Bomb, was accepted by Field Command October 12, 1961. The Mk 28 FI Bomb consisted of a Mk 28 Mod 2 Warhead, Mk 28 Mod 3 Fuze, and Mk 28 Mod 0 Full-Fuzing

Since retarded laydown was desired, the release altitude must be below 12,000 feet pressure altitude, assuring that the baroswitch was closed at release. Laydown was achieved by releasing the weapon at an altitude no lower than 500 feet above the terrain and no higher than 2400 feet, to allow the bomb to reach the ground before the end of the 79-second interval.

At release, the pullout generator was actuated to initiate the low-voltage thermal batteries and start the sequential timer. As the 12-volt sections of the low-voltage batteries came up to voltage (a maximum of 0.7 second after initiation), the differential pressure inducers and the baro ports operated. If the release velocity was greater than the required minimum, the differential pressure induced across the pressure inducers caused the pressure switches to close and connected a set of timer contacts to the activation circuits of the fuse switches. About 0.7 second after pullout-generator actuation, the timer contacts closed and connected the 12-volt sections of the low-voltage thermal batteries to a set of switches and a 60-second pyrotechnic timer, through the closed contacts of the pressure switches and the baroswitch, and to two of the six detonators. These detonators initiated mild detonating fuse which removed the rear cover plate from the bomb. As the cover plate blew off, the 4-foot pilot parachute deployed a 16-1/2-foot-diameter parachute. The 12-volt sections of the low-voltage batteries were meanwhile connected to the contacts of the timer and to the neutron generators.

Approximately 2.4 seconds after pullout generator actuation, a second set of timer contacts closed and connected the 12-volt sections of the low-voltage thermal batteries to a second pair of detonators. These ignited a length of mild detonating fuse which initiated deployment of the second-stage chute. The time of fall from 500 feet above the target altitude was about 10 seconds.

(b)(3)

initiated, but those in the parachute jettison device were activated. The 4-foot pilot chute deployed the 16-1/2-foot chute, and both the 16-1/2- and 64-foot chutes were then jettisoned, and a 30-inch drag chute deployed by action of the jettison device. At the time the chutes were jettisoned, switches were activated, connecting the first set of contacts of the timer to the fuzing circuit. At closure of this timer, explosive switches in the switch pack and the option switches were operated.

(b)(3)

Upon reaching the burst altitude, the baroswitch closed, applying a firing signal to the trigger circuit. If the air-burst option failed, the bomb was detonated at impact by a signal from the impact crystals.

In the free-fall contact option, the fuzing and firing system operated as in the free-fall air-burst option, with some exceptions. Before release, the aircraft monitor and control was placed to the Ground position. This action completed all circuits as in the free-fall air-burst option, except that the firing baro was not connected into the fuzing circuits. At impact, a fire signal was supplied by the impact crystals.[60]

Mk 28 Warhead

(b)(1), (b)(3)

The warhead design was released in June 1957 and achieved early production in August 1958. The Mod 0 Warhead contained an internal initiator.

The Mod 1 Warhead was equipped with external initiation and the first production date was May 1960. The Mod 2 Warhead was strengthened against laydown usage, and the design was first produced in January 1962.[61] The Mod 3 Warhead contained Category A permissive arming links and was first made in [62]

Ground compatibility tests of warhead with missile were begun in April 1959 and satisfactorily completed in July 1959. Flight tests were conducted between late 1959 and early 1961. Restricted use of the Mk 28 Mod 0 Warhead in the HOUND DOG was authorized May 28, 1960, and a general release was issued December 1961.

Report SC4572(WD), Final Engineering Evaluation Report of GAM-77 (HOUND DOG) Application of the Mk 28 Mod 1 Warhead, was dated March 1962. The missile was a turbojet-powered, air-to-ground strategic missile designed for launch from B-52 aircraft. Each airplane could carry two missiles. The missile was of mid-wing canard configuration and had an underslung pod for the jet engine. It had a major fuselage diameter of 28.5 inches, length of 42.5 feet, and major wingspan of 12.3 feet. The missile maximum velocity was Mach 2.1 and its range 650 nautical miles.

Development responsibility for the arming and fuzing system was assigned to North American Aviation. The warhead itself was 20 inches in diameter, 60 inches long, and weighed 1645 pounds with internal initiator and 1675 pounds with external initiator.

The missile had five basic delivery profiles. The high-altitude missile cruise mode could be initiated from either high or low altitude. The same option was available for the low-level cruise mode. A free-fall bomb-drop capability provided an emergency delivery option in the event of missile system malfunction.

The first three steps in the arming and fuzing sequence were independent of missile flight mode. Prior to launch, aircraft power was switched to the safing-switch motors which drove the switches to the Arm position. At launch, pullout-switch closure applied either normal missile power or emergency battery power to the safe-separation timer. The duration of timer operation was dependent on prelaunch setting. At the end of safe-separation interval, timer contacts closed and applied power to either the arming and fuzing baroswitches or the autonavigator. For high-altitude cruise and free-fall modes,

Glossary of Mk 28 Terms

(b)(1), (b)(3)

Department of Defense -- The Armed Forces; i.e., the Army, Navy and Air Force.

Detonator -- Explosive device which, when initiated by the X-unit, ignites the lens charges of the high-explosive sphere.

Deuterium -- The hydrogen isotope of mass number 2.

(b)(1), (b)(3)

Joint Chiefs of Staff -- A group composed of the Chiefs of Staff of the Army, Navy and Air Force to determine policy and develop joint strategic objectives of the Armed Forces.

Kilogram -- A metric weight approximately 2.2 pounds.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

(b)(1), (b)(3)

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Megaton -- A measure of yield of a large weapon. One megaton is the equivalent of 1,000,000 tons of high explosive.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

Nautical Mile -- A naval measurement of length. One nautical mile is equivalent to 6076.1033 feet, or the length of 1 minute of arc (1/21,600) of a great circle of the earth.

Neutron -- An uncharged particle of slightly greater mass than the proton.

Operation Castle -- See Castle.

Operation Greenhouse -- See Greenhouse.

Operation Redwing -- See Redwing.

Operation Teapot -- See Teapot.

Permissive Arming Link -- A device designed to delay or prevent unauthorized personnel from being able to arm and detonate a weapon full scale.

Pit -- The metal sphere at the center of an implosion bomb which received the nuclear capsule when it is inserted.

Plutonium-239 -- A radioactive heavy element, atomic number 94.

Primary -- A fission bomb that acts as the source of energy to start the secondary of thermonuclear reaction of a two-stage device.

Proton -- The nucleus of the atom of the light isotope of hydrogen. It has a unit positive charge of electricity.

Radar -- Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Redwing -- A full-scale nuclear series of 17 tests held at the Pacific Proving Grounds from May 4 to July 21, 1956.

Reservoir -- A container for deuterium-tritium boosting gas.

Ribbon Parachute -- A parachute having a set of ribbons in place of a solid canopy. This type of parachute provides less severe deceleration on deployment.

Rotochute -- A device to slow down the rate of descent of a free-fall weapon. Consists of counterrotating propeller blades which absorb energy.

(b)(1), (b)(3)

(b)(1), (b)(3)

Tactical -- Use of a weapon against troops or concentrations of war materiel.

Teapot -- A less-than-full-scale test series held at the Nevada Test Site. Series of 14 tests, starting February 18 and ending May 15, 1955.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

Thyratron -- A grid-controlled electron tube.

Tritium -- The hydrogen isotope of mass number 3.

Two-Stage -- Combination of fission and fusion action in a weapon.

TX-Theta Committee -- A committee established to guide the development of thermonuclear weapons.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

X-Unit -- A device used to provide high voltage to the weapon detonators.

Yield -- The measure of the effect of a nuclear detonation compared to the effect of an explosion of TNT.

Timetable of Mk 30 Events

Late 1952	Project Heavenbound suggests use of BOMARC missile for atomic warhead carriage.
4/53	Joint Chiefs of Staff issue military requirements for adaptation of XW-12 Warhead to the Air Force BOMARC.
5/15/53	Field Command issues proposed military characteristics for an air defense weapon of 22 inches diameter.
1/5/54	Military Liaison Committee requests consideration of warhead for Navy TALOS missile.
4/13/54	AEC accepts responsibility for developing 22- and 30-inch diameter air defense atomic warheads.
5/4/54	Division of Military Application forwards approved military characteristics for 22- and 30-inch warheads to Santa Fe Operations Office.

(b)(1), (b)(3)

3/12/55	Assistant Secretary of Defense requests AEC to develop XW-30/ TALOS-W missile warhead.
8/29/56	Sandia presents proposed ordnance characteristics report of XW-30/ TALOS-W to Special Weapons Development Board.

(b)(1), (b)(3)

1/58	Mk 30 Mod 0 Warhead released for production.
4/4/58	Assistant Secretary of Defense requests application of Mk 30 Warhead to BOMARC missile.
6/6/58	Feasibility study reports that warhead will be compatible with BOMARC.
Early 1959	Mk 30/BOMARC Warhead program canceled.
4/15/59	Albuquerque Operations Office issues development authorization for XW-30-X1 Tactical Atomic Demolition Munition.

9/25/59	Division of Military Application requests incorporation of environmental sensing devices in Mk 30 Warhead.
11/60	Mk 30 Mod 1 Tactical Atomic Demolition Munition design released.
12/60	Mk 30 Mod 1 achieves production.
3/61	Mk 30 Mod 2 Warhead, with environmental sensing devices, design released.
6/61	Mk 30 Mod 2 Warhead achieves production.
4/64	Mk 30 Mod 3 Warhead, with 5-tumbler combination lock, design released. Later canceled.

History of the Mk 30 Warhead

The Mk 30 was one of three air-defense missile warheads designed concurrently, the others being the Mk 25 and Mk 31. As developing technology permitted the weight of nuclear devices to be reduced and their yields to be increased, it became possible to consider use of nuclear warheads for defense against mass aircraft raids. It was necessary to investigate the effects of high altitudes on operation of these warheads and in late 1952 a feasibility study of air-defense nuclear devices, called Project Heavenbound, was conducted by the Air Force Special Weapons Center. Project Heavenbound determined that BOMARC, a ground-to-air missile being developed by Boeing Aircraft Company for the Air Force, could carry an atomic warhead and, in April 1953, the Joint Chiefs of Staff issued a military requirement for the adaptation of the XW-12 Warhead to BOMARC.[1]

Field Command subsequently prepared a set of proposed military characteristics for an air-defense weapon with a diameter of 22 inches May 15, 1953.[2] These characteristics were largely written around the XW-12 Warhead, although it was evident that this design made inefficient use of nuclear material. The Bureau of Ordnance, then developing a rocket to carry the XW-12, felt that a warhead with higher performance should be chosen, and noted that the missile itself was not entirely suitable.[3]

The Los Alamos Scientific Laboratory could not guarantee an immediate improvement in the XW-12 nuclear design, and Sandia stated that components capable of operating at high altitudes would have to be devised. Sandia was developing a new X-unit which would be operationally suitable but too bulky to fit into the TALOS-W, a Navy missile also being considered for air defense use, and it was felt that any reduction in the size of this X-unit might unduly restrict its electrical characteristics. The warhead could be enclosed in a pressuretight missile compartment, or a sealed warhead provided, but either approach would require a lengthy development program.[4]

As study continued, it became apparent that the XW-12 would require major redesign before it could be used at high altitudes. The proposed military characteristics described an atomic warhead compatible with several delivery vehicles. (b)(3)

not be extended without basic redesign. The new X-unit, which might be able to operate at extremely high altitudes, was undergoing feasibility study, but cables and detonators would also have to be designed for high-altitude operation.[4]

The TALOS-W Coordination Committee met April 2, 1954, and discussed four possibilities for air-defense warheads. The first would be to use the existing XW-12 Warhead with its inherent limitations. The second would be to make minor modifications to this warhead which would improve its altitude capabilities. The third would be to design an interim 22-inch/500-pound warhead using XW-12 components. The fourth would be to design an ultimate 22-inch/350-pound warhead and provide new components.[10]

This information was forwarded to the Military Liaison Committee and, April 13, 1954, the Atomic Energy Commission accepted responsibility for developing both a 22- and a 30-inch-diameter warhead. (b)(1), (b)(3)

The Division of Military Application forwarded the approved military characteristics for 22- and 30-inch antiaircraft warheads to the Santa Fe Operations Office May 4, 1954. (b)(1), (b)(3)

This warhead was to have maximum nuclear efficiency and be compatible with the TALOS-W missile. (b)(1), (b)(3)

Doubt was expressed, however, that a 350-pound warhead could be achieved in a diameter of 22 inches.[13]

3. They would have to be easily maintained. Since personnel handling these weapons would have minimum training, the technical skill for maintenance and operation would have to be kept to a minimum.

The Board noted that the Air Force BOMARC could be used in a national perimeter defense, in conjunction with an early-warning detection system having a range of 250 to 500 miles. However, the BOMARC would not become operational until 1959, and the Navy TALOS-W would be available during the interim period. Both missiles would be capable of carrying either an XW-12 or a 22-inch air-defense warhead.[18]

(b)(1), (b)(3)

The Assistant Secretary of Defense wrote to the Atomic Energy Commission March 12, 1955, requesting development of an XW-30/TALOS-W missile-warhead. The Navy was the cognizant agency, with normal Armed Forces Special Weapons Project relationships. Department of Defense approval of work beyond design release was withheld, pending outcome of further development work.[20]

By early May 1955, the nuclear design of the XW-30 Warhead was determined. The active material was plutonium, and would be fashioned into thin, concentric shells. The design would be boosted with deuterium-tritium gas, externally initiated, and the pit would be sealed to permit operation at high altitudes. It was felt that production could be achieved by early 1958.[21]

The Military Liaison Committee wrote to the Atomic Energy Commission June 15, 1955, stating that the Department of Defense had agreed to increase the overall weight of

the XW-30 to 500 pounds. Concerning the suggestion that the XW-25 Warhead be applied to the TALOS-W, it was noted that the missile had been designed with the XW-30 Warhead in mind, and that any change in warhead would require redesign of the missile.[22]

The Bureau of Ordnance wrote to Santa Fe Operations Office August 12, 1955, noting that development of both missile and warhead would be accelerated if some of the adaption-kit components were developed by Sandia. Sandia was requested to develop an arming and safing system, selectable contact fuze for a surface-to-surface sea capability, contact fuze for surface-to-air missiles striking a target, and a system to dispose of erratic missiles.[23] The responsibility for providing contact fuzes was later transferred to the missile development agency.[24]

By late 1955, considerable progress had been made on the XW-30 nonnuclear design. The warhead length had been fixed at 48.62 inches and the weight at 487 pounds.
(b)(1), (b)(3)

The TALOS-W Coordination Committee met December 14, 1955. Warhead design had been completed, and flight-test units would be available by July 1956. If the required 10 flights could be completed by the end of 1956, the warhead design could be released in January 1957, early production achieved in late 1957, and operational availability in July 1958.[25]

Sandia presented Report SC3842(TR), Proposed Ordnance Characteristics for the XW-30/TALOS-W Warhead Installation, to the August 29, 1956 meeting of the Special Weapons Development Board. The report noted that the TALOS-W was a rocket-launched, ramjet-propelled, supersonic, beam-riding missile designed to intercept and destroy enemy aircraft. It had a range between 2-1/2 and 100 miles, service ceiling of 70,000 feet, and maximum speed of 2400 feet per second (almost Mach 2.5). The total weight of the missile was 7700 pounds, including a solid-fuel booster that separated from the missile some 5 seconds after launch. The missile was 30 inches in diameter and 32 feet long and had a stabilizing wing with a span of 9 feet.

(b)(3)

Meanwhile, consideration had been given to applying the Mk 30 Warhead to the BOMARC and, on April 4, 1958, the Assistant Secretary of Defense suggested that savings in reactor materials could be realized if the Mk 30 were used in this application in place of the XW-40 originally proposed. It was requested that a joint feasibility study be conducted with the Air Force.[36]

The report on this study was released June 6, 1958. (b)(1), (b)(3)

Sandia notified the Division of Military Application, January 2, 1959, that a new warhead development program would be needed to provide BOMARC compatibility, and this would require 3 years before operational availability. This was due to the introduction of several new factors since issuance of the feasibility report, including an extension of armed life, provision of a dudding mechanism, and a more reliable self-destruction system.

It had also been determined that adaptation of the Mk 30 Warhead to the BOMARC was not so simple as initially believed. The lateral type of mounting required by the missile necessitated repackaging of all warhead components, redesign of sphere case, and modification to the electrical system.[38] In addition, use of internal initiation would increase the amount of tritium required[39] and, after consideration of all these factors, the program was canceled.

The Mk 30 military characteristics were amended in February 1959 to specify an unboosted version to be used in a Tactical Atomic Demolition Munition, and a development authorization was issued by Albuquerque Operations Office April 15, 1959, authorizing the XW-30-X1 TADM program. (b)(1), (b)(3)

(b)(1), (b)(3)

A general request had been made by the Division of Military Application for replacement of 3-tumbler combination locks with 5-tumbler designs, to provide a design more resistant to saboteurs. As a result, development of the Mk 30 Mod 3 Warhead was authorized in April 1964. A study of the costs involved resulted in a later decision to cancel this modification, and the change was never incorporated.[46]

Design Review and Acceptance Group -- A Military committee that absorbed some of the functions of the Special Weapons Development Board.

Deuterium -- The hydrogen isotope of mass number 2.

Development Program Definition -- A report that describes the weapon to be designed and the steps that will be taken in its development.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

(b)(1), (b)(3)

Field Command -- The local office of the Armed Forces Special Weapons Project (or Defense Atomic Support Agency), located on Sandia Base, Albuquerque, New Mexico.

Firing System -- The electrical system of the weapon that produces and applies a high-voltage current to the detonators.

Fuze -- A combination of the arming and firing devices of a weapon.

g -- Force equal to one unit gravity.

Gas Boosting -- The technique of increasing the yield of a nuclear device by introducing deuterium-tritium gas into the implosion process to increase the fission activity.

(b)(1), (b)(3)

Joint Chiefs of Staff -- A group composed of the Chiefs of Staff of the Army, Navy and Air Force to determine policy and develop joint strategic objectives of the Armed Forces.

(b)(1), (b)(3)

Reservoir -- A container for deuterium-tritium boosting gas.

Safing -- Putting a weapon in condition such that it cannot fire.

Santa Fe Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with Sandia operations.

Sealed Pit -- A weapon in which all the nuclear components (except the boosting gas) are permanently installed in place. Designed to eliminate the need for inflight nuclear insertion mechanisms.

Services -- The Department of Defense.

Spark Gap -- An air gap that prevents passage of electrical current. When the gap is ionized, current is conducted.

Special Weapons Development Board -- A joint Military-Sandia board at Sandia Base to provide local guidance on weapons design.

Squib -- A device containing a small powder charge. When detonated, the resulting gas pressure closes a switch or performs a similar action. A light, quick-acting, one-shot device.

Supersonic -- Any speed exceeding that of Mach 1.0, which is the speed of sound, or 738 miles per hour at sea level.

(b)(1), (b)(3)

(b)(1), (b)(3)

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

Velocity Switch -- An environmental sensing device whose action depends on the speed environment to which it is subjected.

Warhead -- A weapon carried to the target by missile.

X-Unit -- A device used to provide high voltage to the weapon detonators.

Yield -- The measure of the effect of a nuclear detonation compared to the effect of an explosion of TNT.

Timetable of Mk 31/37 Events

Mid-1953	Development of gas boosting offers possibility of small-diameter atomic devices.
	(b)(1), (b)(3)
4/14/54	Military characteristics for boosted air-defense warheads with diameters of 22 and 30 inches issued.
12/13/54	Army requests that AEC develop Mk 7 and 30-inch-diameter warheads for application to NIKE missile.
1/12/55	Division of Military Application authorizes development of 30-inch-diameter warhead.
3/11/55	Santa Fe Operations Office issues scope of work covering design of adaption kits for XW-7 and 30-inch-diameter warheads for NIKE-B application.
	(b)(1), (b)(3)
6/24/55	Assistant Secretary of Defense requests feasibility study of high-yield warhead for NIKE-B.
8/31/55	Division of Military Application requests development of high-yield warhead for NIKE-B.
	(b)(1), (b)(3)
1/27/56	High-yield XW-37/NIKE-B program approved for development by the Assistant Secretary of Defense.
	(b)(1), (b)(3)
6/27/56	Sandia presents proposed ordnance characteristics of XW-31/37 to Special Weapons Development Board.
9/17/56	XW-31 becomes the XW-31-Y1 and XW-37 becomes the XW-31-Y2. Decision made to use uranium-235 in nuclear assembly of XW-31 rather than composite assembly of uranium-235 and plutonium.

10/18/56 Proposed ordnance characteristics of the XW-31/37 NIKE-B application forwarded to Division of Military Application.

10/25/56 Recommendation made that XW-31-Y2 be authorized for marriage with the HONEST JOHN missile.

11/15/56 NIKE-B nomenclature changed to NIKE HERCULES.

(b)(1), (b)(3)

9/18/57 Design-release report of XW-31 presented to Special Weapons Development Board.

(b)(1), (b)(3)

6/58 Design-release report of NIKE HERCULES adaption kit published.

10/58 Mk 31 Mod 0 NIKE HERCULES becomes operationally available.

10/59 Mk 31 Mod 0/HONEST JOHN becomes operationally available.

6/60 Final evaluation of Mk 31 Mod 0 Warhead published.

6/60 Final evaluation of Mk 31/NIKE HERCULES application published.

Mk 31 Mod 1 (Atomic Demolition Munition)

10/21/58 Military characteristics for the Mk 31 Atomic Demolition Munition issued.

4/15/59 Albuquerque Operations Office issues authorization to proceed with Mk 31 Mod 1 development.

6/60 Design release accomplished.

9/60	Early production started.
12/7/61	Final evaluation report of Mk 31 Mod 1 Munition accepted by Field Command.

Mk 31 Mod 2 Warhead

3/59	Sandia proposes incorporation of handling safety devices in Mk 31 Warheads.
9/59	Military Liaison Committee accepts proposal.
6/62	Mk 31 Mod 2 Warhead design released.
3/63	Early production of Mk 31 Mod 2 Warhead.
9/13/63	Final development report accepted by Field Command.

CROSSBOW Application

9/53	Study of applicable warheads for CROSSBOW missile started.
9/23/54	Marriage program for XW-7/CROSSBOW approved.
11/55	Study report recommends that the XW-31 Warhead replace the XW-7 for the CROSSBOW application.
3/3/56	Assistant Secretary of Defense authorizes development of XW-31 Warhead for use with CROSSBOW.
1/24/57	CROSSBOW application canceled due to missile problems.

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RESTRICTED DATA

UNCLASSIFIED

History of the Mk 31/37 Warhead

This program began in mid-1953, when development of gas boosting offered promise that efficient small-diameter atomic devices might be created. (b)(1), (b)(3)

This design would have to meet requirements of immedate readiness, high-g loading, high-altitude functioning, and maximum economy of fissionable material. (b)(1), (b)(3)

Tentative military characteristics had been proposed by the Military Liaison Committee for boosted air-defense warheads with diameters of 22 and 30 inches, and these characteristics were refined and formally released April 14, 1954.[3] The 22-inch-diameter device became the Mk 30, and the 30-inch-diameter design, which will be discussed in this history, became the Mk 31/37.
(b)(1), (b)(3)

The weapon would be able to withstand single-mission flights of 2 hours and a total flight time of 50 hours, and temperatures from -55°F to +165°F. The firing system would be capable of operation at all altitudes from sea level to 100,000 feet. The nuclear insertion system would provide arming within a period of 6 seconds, and safing within 3 seconds. The weapon would be able to remain in a state of functional readiness for a period of at least 30 days.[4]

SECRET
RESTRICTED DATA

UNCLASSIFIED

This 30-inch-diameter warhead was discussed in a meeting of the Joint Committee on NIKE-B Warhead Installations May 12, 1954. It was felt that the XW-7 high-explosive system could be used, and that no safing problems existed. It was noted that this design would result in fewer restrictions on the missile stockpile-to-target sequence than the XW-7 Warhead.[5]

Subsequently, December 13, 1954, the Army requested that both Mk 7 and 30-inch warheads be developed for NIKE application. This request was forwarded to Sandia by Santa Fe Operations Office as interim guidance, although it was noted that formal Military Liaison Committee approval of the 30-inch warhead marriage program had not as yet been received. However, there was a need for this warhead, even though yield, dimensional characteristics, and identification of carriers were not definite, and the program was placed in full development. It was felt that the Military would eventually replace the XW-7 with the 30-inch design. Thus major effort would be placed on the latter, making certain, however, that a suitable warhead would be ready in time to meet the missile availability date.[6]

The Division of Military Application notified Santa Fe Operations Office January 12, 1955, that the Military Liaison Committee directive of April 14, 1954, had only suggested that the 30-inch warhead might be adaptable to the NIKE-B. This was not considered to represent a firm requirement for the missile-warhead combination, but development of the warhead itself was obviously required.[3]

The warhead was discussed in a Special Weapons Development Board meeting January 12, 1955. The principal purpose of the NIKE-B was surface-to-air attack of enemy aircraft, but it was felt that a secondary surface-to-surface mission would be desirable, having either air or contact burst.

It was noted that high accelerations during nuclear insertion and the requirement for an extremely rapid retraction of the capsule on the downward leg of the flight of a malfunctioning missile would tax the capabilities of existing inflight insertion mechanisms. Air motors, powered by bottles of compressed

air, were being studied, as well as a barrel-cam mechanism whose operation was similar to that of a lipstick container.

Since the missile might be required to make rather rapid changes in direction, some of which might increase the angle of attack of the missile to as much as 30 degrees, a zero angle of attack or swivel probe was required to provide an accurate pressure-sensing system. Barometric accuracy was important, both to initiate nuclear retraction as close to the ground as possible in the event of malfunction in the surface-to-air mission, and to provide a fuze for the possible secondary surface-to-surface mission.[7]

A scope of work covering design of adaption kits for both XW-7 and 30-inch warheads was approved by Santa Fe Operations Office March 11, 1955, and the Assistant Secretary of Defense authorized development of a 30-inch-diameter or XW-31/NIKE-B missile-warhead March 12, 1955.[8,9]

(b)(1), (b)(3)

The basic design of the XW-31 Warhead was now firmed up. (b)(1), (b)(3)

A boosted, sealed-pit system would eliminate any need for capsule retraction. First production was predicted for early 1958.

Accurate pressure sensing was a major requirement, to allow the warhead to be armed at the proper point in the trajectory and detonated at a specific altitude. Testing of supersonic missiles had revealed several major sources of error in existing pressure-sensing systems. Any abrupt changes in the direction of missile travel, and these were inherent in NIKE operation, caused errors, since the axis of the probe which formed the inlet to the barometric system would deviate from the direction of air flow, and thus produce unequal pressures under different angular positions.[7] A self-aligning static tube, with the probe mounted on a universal joint, allowing alignment with the airstream, solved this difficulty.

Plumbing-system pressure lags created time-delay errors, and these time lags were aggravated by the total amount of air contained in the system. This was reduced to a minimum by development of baroswitches with an internal volume of 2.7 cubic inches, as compared to 25 cubic inches in similar devices. At the same time, the diameter of the piping was increased, to reduce the effect of skin friction, which delayed system response.

It was found that cylindrical probes were accurate at speeds up to Mach 1.8, but that errors were introduced above this speed. Tapering of the end of the probe to a 1-degree half-angle solved this difficulty and allowed the probe to be calibrated at all airspeeds up to Mach 5.

By June 15, 1955, preliminary layout of the adaption kit for the warhead installation was completed. This included arm/safe switches and low-volume barometric switches for arming and fuzing. These components, with the necessary relays, connectors and wiring would be installed in a sealed container that could be handled as a unit.[12]

nuclear design would be a hollow, gas-boosted system with external initiation. (b)(3)

This latter would conserve plutonium, then in short supply, and avoid the problems of fabricating thin plutonium shells. Flight tests would start in May 1956, design-release date would be March 1957, and operational availability was scheduled for October 1958.[19]

The Division of Military Application notified Santa Fe Operations Office December 19, 1955, that the Army was considering acceleration of the NIKE-B program. The Military Liaison Committee had requested that Mk 7 development be similarly expedited, to assure warhead availability. (b)(1), (b)(3)

It was felt that this latter device would meet a Joint Chiefs of Staff request for a high-yield air-defense warhead.[20]

On January 27, 1956, development of the XW-37/NIKE-B Warhead was authorized by the Assistant Secretary of Defense. Picatinny Arsenal would represent the Army, and applications to the CORPORAL, HONEST JOHN, SERGEANT and atomic demolition munition would be considered at a later date. Coordination of the project was placed in the hands of the NIKE-B Committee.[21]
(b)(3)

The XW-31/37 would be used primarily for perimeter defense of major population areas and, although the missile batteries would be located some distance away, the warheads could be detonated directly over metropolitan centers.[22] (b)(3)

(b)(1), (b)(3)

(b)(3)

(b)(3)

Meanwhile, sled tests of impact devices had indicated that the best design for fast action and positive indication was a double-shell crush switch located in the nose of the weapon, with piezoelectric crystals pulsing a thyratron trigger circuit. This design had been selected for production, and the missile contractor (Douglas Aircraft Company) was developing a suitable nose compartment. Testing of self-aligning probes were in process, but had encountered instrumentation difficulty which was caused by sensitivity of the vibration pressure pickup to mounting orientation.[25]

A formal feasibility report covering the design of an economical, medium-yield warhead was issued June 1, 1956. (b)(1), (b)(3)

(b)(3)

The gas-boosting system would contain a reservoir containing high-pressure gas, squib-operated valve, and associated tubing. A pit vacuum monitoring system would check for existence of leaks which would degrade the yield through atmospheric corrosion of the nuclear material. Provision would be made to detect tritium leakage during storage or handling, since this gas was a health hazard. (b)(1), (b)(3)

Sandia presented Report SC3752(TR), Proposed Ordnance Characteristics of the XW-31/37 (NIKE-B Application) Atomic Warhead Installation, to the June 27, 1956 meeting of the Special Weapons Development Board.[1] (b)(1), (b)(3)

Both warhead and adaption kit were sealed with the cartridge assembly containing most of the adaption-kit components being attached to the warhead.

(b)(1), (b)(3)

An impact switch held two metal rings mounted inside the weapon nose and insulated at points of contact with the skin. When the skin was crushed against the ring at weapon impact, a firing circuit was completed and the warhead detonated. (b)(3)

The Board accepted the report, subject to inclusion of a warhead reliability study. This information was provided and forwarded to the Division of Military Application October 18, 1956.[27]

By July 1956, systems design of the XW-31/37 Warheads had been completed. Four more sled tests had been performed, and the deformation switch was deemed to be completely satisfactory for NIKE-B impact fuzing applications. Sandia meanwhile had recommended that weapons with multiple yields be assigned a single Mark designation, and that a suffix be used to indicate the yield. This proposal was accepted by Field Command September 17, 1956; the XW-31 thus becoming the XW-31-Y1 and the XW-37 becoming the XW-31-Y2.[28] At this time it was definitely decided to use uranium-235, rather than a composite nuclear system, to conserve plutonium.

Meanwhile, some thought had been given to compatibility of the warhead with the HONEST JOHN missile. The Joint Committee on HONEST JOHN Warhead Installations met October 25, 1956. A longer range version of this missile had been proposed, and a recommendation made that the higher yield XW-31 Warhead be mated to this missile rather than the Mk 7. The longer range HONEST JOHN would have a higher acceleration, and it was felt that the XW-31 would be better able to resist this acceleration.[29] The recommendation was accepted and forwarded to Washington.

NIKE-B missile nomenclature was changed to NIKE HERCULES November 15, 1956, and the intercept capability of the NIKE system was increased from 25 to 50 miles. The Mk 7 flight-test program had meanwhile been delayed due to missile problems, and flight tests with the XW-31-Y2 Warhead were rescheduled to January 1957. It was hoped that the eight flights required for warhead certification could be completed before the scheduled design-release date of June 1957.[30]

(b)(1), (b)(3)

Development was requested of all three warhead combinations, and the Department of the Army was designated cognizant agency for the Department of Defense.[31] An operational availability date of July 1959 was desired, but would depend on the availability of nuclear material.[32]

The Joint Committee on HONEST JOHN Warhead Installations met February 7, 1957. The longer-range rocket promised improvements in deflection, altitude and range accuracy. The rocket weight would be reduced by 1000 pounds and the length by 3 feet through use of a new propulsion unit being developed by Redstone Arsenal, and this would increase the rocket range by 15 percent. Picatinny Arsenal was developing an adaption kit, and it appeared that the XW-31 Warhead could be used with either the old or the improved HONEST JOHN.

(b)(1), (b)(3)

The weight would be identical in all yields, as the lighter versions would be ballasted to that of the heaviest. It was felt that the transistorized power supply of the external initiators might cause trouble, due to sensitivity of these transistors to neutron radiation, and Los Alamos agreed to consider use of internal initiation for some of the XW-31 yields. This would simplify development effort, provide operational simplicity, and allow more positive control of time scales.[33]

(b)(1), (b)(3)

(b)(1), (b)(3)

Report SC4099(TR), Description and Status at Complete Design Release of the XW-31 Warhead, was presented to the September 18, 1957 meeting of the Special Weapons Development Board. The warhead was 29.01 inches in diameter, 39.05 inches long, and weighed 920 pounds. The warhead was compatible with both NIKE HERCULES and HONEST JOHN missiles.[40] (b)(1), (b)(3)

The report was subsequently forwarded to the Division of Military Application February 26, 1958.[42] The Mk 31Y2 Warhead design was released in November 1957, when the external initiator became available.[43] Subsequently, external initiators were deleted from the Y1 and Y3 versions, leaving the Y2 with an external neutron generator.[44]

Meanwhile, the Army Air Defense Board had noted that there was a high probability of receiving a premature command signal from the missile guidance system in the surface-to-surface mode. This was a safety hazard, as it disabled the self-destruct system. If the missile was fired straight up, the warhead would be armed and, when it returned, the warhead would detonate at the fuzing altitude.[45]

This problem was discussed in the November 5, 1957 meeting of the Joint Committee on NIKE HERCULES Warhead Installations, and it was decided that the best solution was to install a timer in parallel with the command signal. Since it was desired that this timer not interfere with the reliability of

the primary surface-to-air mission, it should not be incorporated in the guidance-equipment package, and Sandia agreed to place it in the adaption kit. Development of the timer was started immediately, and would be included in the system only when a surface-to-surface plug was installed.[46]

(b)(3)

Meanwhile, difficulties had been encountered on both missile programs. The HONEST JOHN adaption kit slipped 3 months, due to lack of funding.[48] The NIKE HERCULES changed from liquid to solid propellant, and this created difficulties.[49]

(b)(1), (b)(3)

A suitable timer was installed in the warhead, and the guidance computer modified.[50]

Report SC4099(TR), Description and Status at Design Release of the XW-31 Warhead, was released January 1958 by Sandia. This noted that partial design release of the Mk 31 with the Y1, Y2 and Y3 had been accomplished in June 1957, with complete release scheduled for November 1957.[41] (The actual date was March 1958.)

The report noted that the NIKE HERCULES was a two-stage missile, with a solid-propellant booster and sustainer. The sustainer motor ignited when the booster separated (about 35 seconds after launch) and powered the missile for about 32 seconds. After burnout, the missile coasted to the intercept point. Flight duration was between 10 and 200 seconds. The missile was guided throughout its flight after initial boosting.[41]

(b)(1), (b)(3)

Report SC4243(WD), Final Evaluation Report of the Mk 31 Mod 0 Warhead, was published in June 1960. This noted that the sequence of operation was unchanged from that described in the report at design release.[44] On the same date was published Report SC4242(WD), Final Engineering Evaluation of the M75 Adaption Kit and the Mk 31/NIKE HERCULES Application. This noted that the missile was capable of intercepting aircraft formations at ranges in excess of 50 miles and above 80,000 feet altitude with a circular error of 40 yards at a range of 50 miles. The missile was ground-guided to the target by a computer, which also furnished the burst command. The missile had a single solid-propellant sustainer motor and a solid-propellant booster of four NIKE AJAX Jato's.[50]

The sustainer motor ignited when the booster separated (which was 3 to 4 seconds after launch) and burned for about 30 seconds. After burnout, the missile coasted to intercept. Intercept time varied from 20 to 200 seconds, and the missile was controlled in flight by aerodynamic surfaces on the trailing edges of the four fins which extended along approximately four-fifths of the length of the missile.[50]

Atomic Demolition Munition (Mk 30 Mod 1 Warhead)

The Mk 30 Mod 1 Warhead was designed to fulfill the requirements for the application of the Mk 31 Warhead as an Atomic Demolition Munition. The principal requirements were set forth in the military characteristics dated

October 21, 1958.[60] Authorization to proceed with development was received from Albuquerque Operations Office April 15, 1959.[61]

Some attention had been given to the desirability of incorporating environmental sensing devices in the Mk 31 (see the Mod 2 description) and for a time it was felt that these devices should also be applied to the munition. However, November 12, 1959, the Military Liaison Committee decided that field conversion of Mk 31 Warheads to atomic demolition munition use would not be required. It thus became possible to apply the Mod 2 only to Mk 31 Warheads for missile use. However, a combination lock was required, to provide handling safety for the munition.[62]

Design release of the Mk 31 Mod 1 Atomic Demolition Munition was accomplished in June 1960 and early production in September 1960. In order to meet this date, a lock-secured cover was completely developed in a relatively short time scale. In addition, a thermal plug was incorporated in the boosting-gas-reservoir system which provided added safety in the event that the munition was subjected to a fire environment.[60]

The outside diameter of the Mk 31 Mod 1 was 29.01 inches, length 43.75 inches, and weight 925 pounds. Y1, Y2 and Y3 yields were provided. Report SC4507(WD), Final Evaluation Report of the Mk 31 Mod 1 Warhead,[60] was reviewed in coordination with the interested Services and accepted by Field Command December 7, 1961.[63] It was noted that the design met all requirements of the military characteristics except for a slightly less than desired reliability figure. The report was forwarded to the Division of Military Application February 19, 1962.[64]

Mk 30 Mod 2 Warhead

The advent of sealed-pit weapons and the emphasis on immediate operational readiness for air-defense devices had greatly accentuated the need for safety.[65] Protection was required, both against accidents during warhead testing and the deliberate actions of a saboteur or psychotic. Sandia accordingly conducted an investigation and, March 1959, proposed incorporation of a handling safety device in all Mk 31 Warheads.

This device was a velocimeter consisting of a cylinder having a piston with orifices, a pair of normally open operating contacts, and latching and reset features. A breakaway mass was held in place by a restraining spring and a small magnet, and could be separated by applying a force of 2.5 g's. The piston then operated, and the contacts closed and latched.

In April 1959, the Division of Military Application proposed that handling safety devices be added to all Mk 31 Warheads and, September 1959, the Military Liaison Committee requested such incorporation. After design work, Sandia suggested use of an inertial switch, and final approval to proceed with this change was released October 1961. Since production of Mk 31 Mod 0 Warheads was essentially complete at that time, it was decided to retrofit the Y2, Y3 and Y4 warheads in the field at the time their boosting-gas reservoirs were replaced. Y1 warheads would be retrofitted whenever the weapon had to be disassembled for any reason.

Complete engineering release for the Mk 31 Mod 2 Warhead was dated June 1962. Early production of the Y2, Y3 and Y4 inertial switch pack for retrofit was March 1963, and early production of the Y1 switch pack was August 1963. Report SC4782(WD), Final Development Report for the Mk 31 Mod 2 Warhead, was reviewed and approved by Field Command September 13, 1963,[66] and forwarded to the Division of Military Application November 22, 1963.[67]

(b)(1), (b)(3)

Different inertial switch packs, differing only in detail, were used in the two applications. In normal operation, the warhead could not become completely armed until it had experienced a specified flight environment for a certain minimum time.[68]

CROSSBOW Application

Some consideration was given to application of the Mk 31 Warhead to the CROSSBOW, an Air Force air-to-surface missile designed to destroy enemy ground

radar installations. The missile, designed and built by the Radioplane Company of Van Nuys, California, would be flown to the launch zone by B-47 or B-52 bomber. The operator in the bomber, after acquiring enemy radar signals, would lock the missile's guidance system on this target. The missile could be released as far as 250 nautical miles from the target and would home on the radar station, detonating on contact.[69]

Study of applicable warheads was started in September 1953 and it was initially decided that either XW-7 or XW-12 use would require relocation of the air induction system and a redesign of the warhead compartment, and that new fuel tanks would have to be provided. Subsequently, however, a more detailed study was conducted and concluded that the XW-7 Warhead could be used. A marriage program for the XW-7/CROSSBOW was approved by the Military September 23, 1954, and Atomic Energy Commission support solicited.

This participation was delayed but, July 11, 1955, the AEC agreed to provide certain fuzing components and consultant services, which were made available by the fall of 1955. Subsequently, use of the XW-31 Warhead was suggested and a feasibility study conducted.[70] The study report was dated November 1955 and recommended that the XW-31 Warhead be used, due to its higher nuclear efficiency and reduced need for support and surveillance, as compared to the XW-7.[71]

(b)(1), (b)(3)

However, difficulties with the missile led to cancella-
made [73]

Deuterium -- The hydrogen isotope of mass number 2.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

(b)(1), (b)(3)

Field Command -- The local office of the Armed Forces Special Weapons Project (Defense Atomic Support Agency as it was later called), located on Sandia Base, Albuquerque, New Mexico.

Firing System -- The electrical system of the weapon that produces and applies a high-voltage current to the detonators.

Fuze -- A combination of the arming and firing devices of a weapon.

g -- Force equal to one unit gravity.

Gas Boosting -- The technique of increasing the yield of a nuclear device by introducing deuterium-tritium gas into the implosion process to increase the fission activity.

Guided Missile -- A missile that is directed to its target while in flight or motion, either by a preset self-reacting device within the missile or by radio command outside the missile.

Hardtack -- A nuclear series of 72 tests. Hardtack I was held at the Pacific Proving Grounds from April 28 to August 18, 1958. The decision to declare a moratorium on testing resulted in Hardtack II, held at the Nevada Test Site between September 12 and October 30, 1958.

High-Explosive Sphere -- The ball of high explosive that surrounds the nuclear assembly and is designed to produce the implosion effect when detonated.

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(b)(1), (b)(3)

Jamming -- The practice of defeating radar by providing spurious responses in enemy equipment. Jamming can be passive or active.

Jato -- Named for Jet-Assisted Take-Off. A jet device initially designed to assist heavily loaded aircraft to take off from short runways. Used as a boosting device in missile launching.

Joint Chiefs of Staff -- A group composed of the Chiefs of Staff of the Army, Navy and Air Force, to determine policy and develop joint strategic objectives of the Armed Forces.

Joint Committee on HONEST JOHN Warhead Installations -- A committee, with representatives from nuclear, warhead and missile designer, and the Military, established to guide the activities related to the HONEST JOHN Warhead.

Joint Committee on NIKE-B Warhead Installations -- A committee, with representatives from nuclear, warhead and missile designer, and the Military, established to guide the activities related to the NIKE-B Warhead.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Lenses -- As applied to nuclear weapons, lenses are elements of the high-explosive sphere, which are designed to produce an implosion. The lens charge is composed of high explosives of different burning rates and is so constructed and shaped as to change the explosion initiated by the detonators into an implosive force which converges smoothly on the nuclear materials.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico.

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

Nautical Mile -- A naval measurement of length. One nautical mile is equivalent to 6076.1033 feet, or the length of 1 minute of arc (1/21,600) of a great circle of the earth.

Neutron -- An uncharged particle of slightly greater mass than the proton.

Nuclear Insertion -- Insertion of the nuclear capsule when the weapon is ready to be armed for detonation. An atomic weapon with a retracted capsule is relatively safe, and will only produce a yield equivalent to the amount of high explosive in the weapon if the arming and fuzing sequence was initiated and went to completion.

(b)(3)

(b)(1), (b)(3)

Radar -- Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Redstone Arsenal -- An Air Force arsenal, responsible for design of large rockets.

Reservoir -- As used in this history, a container for deuterium-tritium boosting gas.

Retrofit -- To modify a weapon, i.e. "retroactively outfit" it with changed material.

Safing -- Putting a weapon in condition such that it cannot fire.

Santa Fe Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with the Sandia operations. Renamed Albuquerque Operations Office, April 2, 1956.

Sealed Pit -- A weapon in which all the nuclear components (except the boosting gas, when used) are permanently installed in place. Designed to eliminate the need for inflight nuclear insertion mechanisms.

Special Weapons Development Board -- A joint Sandia-Military board at Sandia Base to provide local guidance on weapons design.

Squib -- A device containing a small powder charge. When detonated, the resulting gas pressure closes a switch or performs a similar action. A light, quick-acting one-shot device.

Supersonic -- Any speed exceeding that of Mach 1.0, which is the speed of sound, or 738 miles per hour at sea level.

Teapot -- A less-than-full scale test series held at the Nevada Test Site. Series of 14 tests, starting February 18 and ending May 15, 1955.

Telemetry -- The transmission of signals from a moving or distant object.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thyratron -- A grid-controlled electron tube.

Ton (Yield) -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-ton yield is equivalent to the detonation effect of 2000 pounds of high explosive.

Transistor -- A nonvacuum electronic device having uses similar to the electron tube, whose control of current is accomplished by the conductive properties of a semiconducter such as germanium.

Tritium -- The hydrogen isotope of mass number 3.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

Warhead -- A weapon carried to the target by missile.

X-Unit -- A device used to provide high voltage to the weapon detonators.

Yield -- The measure of the effect of a nuclear detonation compared to the effect of an explosion of TNT.

References

1. (b)(3)

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4. SRD Ltr, Field Command to Distribution, dtd 5/18/54, subject, Transmittal of Military Characteristics. AEC Files, MRA-5, 5/54-6/54.

5. (b)(3)

6. SRD Ltr, Santa Fe Operations Office to Sandia Corporation, dtd 12/23/54, subject, NIKE-B Warhead Development. AEC Files, MRA-5, NIKE, 7/54.

7. SRD Minutes, RS 3466/84055, Special Weapons Development Board to Distribution, dtd 1/12/55, subject, Minutes of 89th Meeting, Part I. SC Archives, Transfer No. 48217.

8. (b)(1), (b)(3)

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10. (b)(3)

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41.

(b)(3)

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47.

(b)(3)

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49. SRD Report, RS 1247/112, Division 1247 to Department 1240, Sandia Corporation, dtd 12/9/57, subject, Trip Report, 14th Meeting of the Joint Committee on NIKE HERCULES Warhead Installations. SC Central Technical Files, XW-31/NIKE HERCULES, 1956-7.

50.

(b)(3)

51. SRD Ltr, RS 1000/3237, Sandia Corporation to Albuquerque Operations Office, dtd 3/13/58, subject, XM-50 HONEST JOHN Missile Program. SC Central Technical Files, XW-31/HONEST JOHN.

52. SRD Ltr, Division of Military Application to Albuquerque Operations Office, dtd 3/27/58, subject, XM-50 HONEST JOHN Program. AEC Files, MRA-5, HONEST JOHN, 7/57.

53. SRD Minutes, Joint Committee on NIKE HERCULES Warhead Installations to Distribution, dtd 4/10/58, subject, Minutes of 15th Meeting. AEC Files, MRA-5.

54. (b)(1), (b)(3)

55. SRD Report, RS 3466/26793, Sandia Corporation to Distribution, dtd 6/58, subject, Report SC4097(TR), Description and Status at Design Release of the M75 Adaption Kit. SC Reports Files.

56. (b)(3)

57. SRD Minutes, Joint Committee on HONEST JOHN Warhead Installations to Distribution, dtd 5/14/59, subject, Minutes of 17th Meeting. AEC Files, MRA-5.

58.

59. (b)(3), (b)(1)

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63. SRD Ltr, RS 3446/45910, Field Command to Sandia Corporation, dtd 12/7/61, subject, SC4507(WD), Final Development Report of the Mk 31 Mod 1 Warhead. SC Central Technical Files, Mk 31, 1961.

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The Chief of Naval Operations wrote to the Bureau of Ordnance September 15, 1955, noting that a laydown bomb family with the range of yields noted above might require two different nuclear designs. One would be the single-stage XW-34 and the other might be an adaptation of the Mk 28 thermonuclear bomb.[14]

The military characteristics for the XW-34/LULU depth bomb were approved by the Military Liaison Committee October 4, 1955.

(b)(1), (b)(3)

The length and weight of the weapon would be held to a minimum, and not exceed 26 inches and 300 pounds, respectively.

The power supply would be a thermal battery. Since incorporation of this type of cell in a sealed package was undesirable from the standpoints of safety and surveillance, the battery would be located outside the sealed package. The operational requirements dictated that the depth bomb be capable of remaining in a completely assembled and ready-for-use condition, without loss of reliability, for a period of at least 180 days or 1000 flight hours, whichever occurred first. The weapon would be able to withstand linear accelerations of -2000 g's and +100 g's along the longitudinal axis, an acceleration of 800 g's along any axis perpendicular to the longitudinal axis, and angular accelerations about the longitudinal axis of 300 radians per second per second.[15]

The Assistant Secretary of Defense wrote to the Atomic Energy Commission October 6 1955, requesting that LULU and HOTPOINT feasibility studies be combined.[16]

(b)(1), (b)(3)

The initial step in this project would be to develop a bomb with a weight not over 1500 pounds and having a time-delay feature to permit release from very low altitudes and allow safe escape of the delivery aircraft.[17]

The Special Weapons Development Board discussed the laydown program in a meeting October 26, 1955. The feasibility study would be completed by December 1956, and

impacts with such targets as aircraft runways. A feasibility study was started on this design, which became the Mk 34 weapon.

The Step II weapon would be capable of being delivered at low altitudes by low-angle pitch-off or over-the-shoulder tactics. Fuzing would be air burst with a contact cleanup option. There would be preflight selectability between timer and radar, and inflight choice between radar and contact options. The air-burst height would be such as to eliminate severe residual contamination.

(b)(1), (b)(3)

Delivery would be by Navy AD4 aircraft. This Step II weapon became the Mk 28 Mod 2 Bomb.

The Step III weapon was a long-term development combining the characteristics of Steps I and II, and it would depend on future design progress. The device would be capable of delivery at both low and high altitudes and at speeds over Mach 0.9.

(b)(1), (b)(3)

This design would provide the Services with a single weapon or weapon family having tactical fuzing capabilities of air burst, ground contact, and delayed laydown options. This design became the Mk 43 Bomb.[20]

(b)(1), (b)(3)

Sandia forwarded the product definition for the XW-34 to Santa Fe Operations Office February 13, 1956. It was anticipated that the design could be released in April 1957, with early production in the second quarter of calendar year 1958.

(b)(3)

(b)(3) The overall depth bomb would be 18 inches in maximum diameter and 96 inches long, and would weigh about 1200 pounds. The depth bomb would be capable of internal or external carriage and delivery from low altitudes. Both timer and hydrostatic pressure fuzes would be provided.

Sandia would be responsible for nonnuclear bomb components and any associated test and handling equipment. The Naval Ordnance Laboratory would be responsible for the LULU adaption kit, including pressure hull and fuzing and arming system. The high-explosive case would be an aluminum sphere consisting of two caps with a center seal, and would be enclosed by the pressure hull. The battery assembly would contain five permanently potted thermal cells connected in series with an output of 2500 volts. An arm/safe switch would incorporate a motor, low- and high-voltage switches, and requisite circuits and hardware, all enclosed in a metal container. This switch could be operated by the pilot of the carrying aircraft through application of aircraft power.[22]

By early 1956 work was in progress on several components to be used in the Xw-34 program. One was a low-voltage thermal battery, with the capability of firing a squib switch and matches in the high-voltage thermal batteries, and of pulsing the X-unit gap. A battery life of 100 seconds was desired, and it was believed that a 28-volt thermal cell being developed by the Naval Ordnance Laboratory would be suitable. Another component was a switch whose contacts were closed until a deceleration of at least 15 g's was experienced. Another set of contacts were closed until a deceleration over 20 g's was experienced.

A safe-separation timer with a fixed time of 17 seconds and a fuzing timer with a fixed time of 6.25 seconds were needed, and it was felt that pyrotechnic devices being developed by the Naval Ordnance Laboratory could be used. Since there was only limited space available for the fuzing system, each component would have to be as small as possible. The fuze would be potted to withstand the shock of water entry.[23]

(b)(1), (b)(3)

Revised military characteristics for the LULU depth bomb were released by the Military Liaison Committee March 27, 1956. These noted that the weapon was a small-diameter, lightweight atomic bomb to be used in attack of submarines by carrier-based aircraft. The immediate objective was a weapon with some delivery restrictions and available for operational deployment April 1, 1958. The ultimate objective was a weapon capable of unrestricted delivery, including an ability to be dropped into shallow bodies of water and operate satisfactorily.

The maximum speed for external carriage was 300 knots, and the maximum launch altitude was 600 feet.

(b)(1), (b)(3)

It was hoped that the weapon would maintain reliability for at least 1000 flight hours. This would include three patrols per day, each of 4-hour duration, for a period of 90 days. Each patrol would start with a catapulted takeoff and end with an arrested landing.[25]

Report SC3759(TR), Proposed Ordnance Characteristics of the XW-34 Warhead for the LULU Depth Bomb,[26] was discussed in the 100th meeting of the Special Weapons Development Board held April 25, 1956, and this report was subsequently forwarded to the Division of Military Application.

(b)(1), (b)(3)

If the weapon was dropped into shallow water, it would be detonated by timer.

The watertight pressure hull of the LULU could withstand 1000-pounds-per-square-inch water pressure. The hull was internally pressurized with a dry gas at 5 or 10 pounds per square inch, and any need for desiccant was thus eliminated. The afterbody was

an aluminum sheet-metal cone perforated for rapid flooding. Two pieces of handling equipment were required, a storage/shipping container and a handling sling. Two test sets were designed, one to monitor the electrical circuits and the other to detect leakage of deuterium-tritium gas.

(b)(1), (b)(3)

The X-unit held four capacitors, dual-probe gap, and two gap trigger transformers. The high-voltage battery package contained five thermal batteries, two battery squib transformers, two thermal fuses, five silicon diode nets and two monitor switches.

A battery monitoring device indicated whether the thermal batteries had been fired. Thermal fuses were mounted near the outside edge of the potting and would melt in the event of aircraft fire before the battery heat-powder matches could ignite. Silicon diodes were installed in parallel with each battery to allow by-passing of defective units.

Special safety provisions were furnished. A safing plug grounded the boosting system, high-voltage battery initiation squibs, and all low-voltage pins. The high-voltage battery pack was not installed until preflight operations were in progress. The inflight safing switch opened the high-voltage circuit and grounded the capacitor bank, and the switch remained in this position until just before bomb release. A hydrostat switch in the adaption kit blocked arming and firing signals until it closed at the proper water depth.

The Navy desired that the weapon be compatible with all carrier-based aircraft planned through 1960. Requirements were for launches from altitudes of 0 to 600 feet and at release speeds of 0 to 300 knots; and it was hoped that launches could be made at altitudes as high as 2000 feet and speeds up to 600 knots. In water of less than 20-foot depth, a launch altitude of 150 feet and speed of 150 knots were specified.

(b)(1), (b)(3)

It was felt that the best way in which to provide this weapon, which could be delivered from low altitudes and high speeds with good accuracy, was through modification of the LULU design.

Subsequently, the Assistant Secretary of Defense wrote to the Atomic Energy Commission, September 19, 1956, noting that the feasibility study of a tactical/lay-down weapon family had been completed.

(b)(1), (b)(3)

Thus, in order to satisfy urgent requirements, it was requested that the Atomic Energy Commission cooperate with the Navy in the development through production of the XW-34/HOTPOINT. This weapon would

utilize LULU depth-bomb components, modified to increase shock resistance, and the Navy was assigned cognizance of the Department of Defense portion of the work.[28] Albuquerque Operations Office subsequently established a tentative operational availability date of October 1958.[29]

(b)(1), (b)(3)

The LULU Coordinating Committee replied that there appeared to be two methods for accomplishing this result.

(b)(1), (b)(3)

A meeting was held December 4 1956 with personnel of the Applied Physics Laboratory of the University of Washington, to discuss possible atomic devices for an antisubmarine torpedo, the ASTOR. This torpedo was 19 inches in diameter and 20 feet long.

(b)(1), (b)(3)

Atomic devices that could be applied to the ASTOR included the XW-34, XW-40 and possibly XW-25.[33]

Sandia wrote to Albuquerque Operations Office April 8, 1957, noting that there might be some logistical advantage to be gained by applying XW-34 to ASTOR.[34] Subsequently, the Assistant Secretary of Defense, May 14, 1957, requested the Atomic Energy Commission to proceed with development engineering adaption of the XW-34 to ASTOR.[35] Since the ASTOR would only have to withstand 60-g shock, 3-g vibrational environment, and a temperature range from -65°F to +130°F, the XW-34 could be used without modification.[36]

Identification of Mk 101 Mod 0 Depth Bomb had meanwhile been assigned to LULU, and production nomenclature of Mk 34 Mod 0 to the warhead.[37,38] The Mk 34 design was released in May 1957, with the exception of external initiators and final-assembly tester.[39] These items were released by October 1957.

The HOTPOINT weapon was discussed in the June 20, 1957 meeting of the Special Weapons Development Board. Target approach could be made at minimum altitude, which made detection of carrying aircraft difficult. Since delivery and escape maneuvers placed minimum burden on the pilot, special flight skill and training were not needed, and aircraft safety was enhanced. Attacks could be made from any direction, since an identification point was not necessary, and target identification became more positive. There were, of course, some disadvantages. The surface burst of the weapon produced ground contamination, and the combination of low-altitude and high-speed flight consumed aircraft fuel at a high rate. However, the advantages far outweighed the disadvantages.

(b)(1), (b)(3)

The weapon would be 19 inches in diameter, 162 inches long, and weigh about 1400 pounds. The tail cone would be explosively jettisoned 1/4 second after release of the bomb from the carrying aircraft, and an extraction parachute deployed. Another 1/4 second later, the afterbody would be detached by detonation of explosive bolts and pulled away from the weapon by the extraction parachute, thus releasing the main parachute.

Since LULU had been designed to withstand axial deceleration of 2000 g's combined with lateral shocks of 800 g's, it was felt that a suitable laydown weapon could be

(b)(1), (b)(3)

It was felt that the HOTPOINT was a good interim weapon. There were practically no limitations on the low-altitude delivery capability of the system, and the weapon was demonstrably rugged. In one test, the main parachute failed when the bomb was dropped from an altitude of 67 feet and a speed of 510 knots. A bomb containing live high explosive struck the ground with an impact velocity of 650 feet per second and slammed 3500 feet down a concrete runway before stopping. The drop was a severe overtest of the entire system but only minimal damage resulted, and the unit would have fired successfully.[42]

Meanwhile, LULU testing had been proceeding. Drop tests were made to determine that the weapon would enter the water at low angles without ricocheting. In 25 drops, angles from 6 to 30 degrees were tested at weapon impact speeds of 300 to 550 feet per second. Satisfactory results were obtained, as well as those from several hundred air-gun tests on components and assemblies.[43]

A cookoff test was conducted, in which the weapon was subjected to a gasoline fire for a period of about 30 minutes. During this test, temperatures as high as 1650°F were recorded, and there was a low-order explosion of the weapon after more than 13 minutes of fire. Test results indicated that there would be ample time to take necessary action in the event of fire following an airplane crash.[44]

Water drops of inert LULU weapons were conducted with extremely satisfactory results.[45]

(b)(1), (b)(3)

(b)(1), (b)(3) The shock resistance of the weapon exceeded all expectations and no damage to fuzing or firing systems was recorded. Additional water drops were made, with the weapons being subjected to temperature and humidity preconditioning. In these tests, which used weapons progressively closer to full production status, equally satisfactory results were obtained.

(b)(1), (b)(3)

It was the opinion of the Committee that the LULU met or exceeded the military characteristics.

The capability for bomb release at altitudes of less than 50 feet had not been conclusively proven, as the tail of one test aircraft had been hit by the water splash of the bomb when released from this altitude, and testing at this height had been subsequently discontinued.

(b)(1), (b)(3)

These drops were highly successful.[49]

The Mk 34 Mod 0 Warhead was design-released for use in LULU July 28, 1958.[50] Report SC4155(TR), Final Evaluation of the Mk 34 Mod 0 Warhead (LULU Application),[51] was presented to the August 20, 1958 meeting of the Special Weapons Development Board. The device was designed primarily for application in the LULU depth bomb, but could also be used with the ASTOR and HOTPOINT weapons.[52]

Meanwhile HOTPOINT testing had been proceeding. Air-gun firings were made, using live high-explosive spheres and simulated nuclear assemblies in some cases, and simulated spheres and live nuclear assemblies in others. The target was a concrete slab, and impact velocities ranged from 180 to 250 feet per second and impact angles from 8 to 60 degrees. One aluminum battery housing was ruptured during tumbling of the bomb after impact, and this material was changed to steel. An external initiator was included in the most severe test in the series and resulted in a cracked electronic tube and a slow leak, but the weapon probably would have functioned at the time of impact.[53]

Production authorization for the Mk 34/ASTOR was issued in March 1959, and an operational date of October 1960 was established. Since the ASTOR environment was much less severe than that of LULU and HOTPOINT, only a few tests were required to prove compatibility.[60] These included environmental tests of the torpedo compartment containing the Mk 34 and electrical tests of the system. A series of four fuzing and firing runs of the complete torpedo and Mk 34 were successfully conducted in mid-1959.

Report SC4750(WD), Final Evaluation of the Mk 34 (Mods 2, 3 and 4) Warhead to the Mk 45 (Mods 0 and 1) Torpedo (ASTOR), was published in June 1963. This report noted that at the time of development authorization, the torpedo was scheduled to be operational in the spring of 1960. Due to budget restrictions, the operational date was delayed until late 1962. The first release of the warhead for use in the ASTOR was October 10, 1960, with the Mk 34 Mod 1 (see later paragraphs for Mod 1 description) Warhead. Later, the Mods 2, 3 and 4 were also released for ASTOR use, and eventually a decision was made to use only the Mods 3 and 4.[61]

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The bleeder resistors were placed in the neutron generators.

It was later decided to install a shielded pullout cable and a filter pack in the electrical circuit to attenuate any induced currents. The bleeder resistor was changed to 15 ohms, and this change constituted the Mk 34 Mod 3. A still further change, this time back to the 30-ohm bleeder resistors, resulted in the Mk 34 Mod 4 Weapon.[65]

Depth Bomb -- An explosive charge that detonates after sinking to a prescribed depth in water.

Detonators -- Explosive devices which, when initiated by the X-unit, ignite the lens charges of the high-explosive sphere.

Deuterium -- The hydrogen isotope of mass number 2.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

Drogue Parachute -- A parachute that slows the rate of fall of a bomb.

Explosive Bolt -- A bolt containing a small charge of explosive. When detonated, the bolt fractures.

(b)(1), (b)(3)

Firing System -- The electrical system of the weapon that produces and applies a high-voltage current to the detonators.

Fuzing System -- The system that arms the weapon at the appropriate time and provides a firing signal to the firing system at the selected burst height.

g -- Force equal to one unit gravity.

Gap Switching -- An air gap normally prevents passage of electrical current. When this gap is ionized, it will act as a conductor.

Gas Boosting -- The technique of increasing the yield of a nuclear device by introducing deuterium-tritium gas into the implosion process to increase fission activity.

Gun-Type Design -- An atomic weapon based on the principle that a supercritical mass of nuclear material can be created by bringing together two subcritical masses of such material.

High-Explosive Sphere -- The ball of high explosive that surrounds the nuclear ~~primary~~ and is designed to produce the implosion effect when detonated.
fuzt and capsule

Hydrostat -- A pressure switch which closes at a prescribed water depth.

Implosion -- The effect created when a sphere of high explosive is detonated on it exterior surface. If suitable lens charges are provided to invert the explosion, the force of the shock wave is directed largely toward the center of the sphere.

Initiator -- A source of neutrons.

Joint Chiefs of Staff -- A group composed of the Chiefs of Staff of the Army, Navy and Air Force to determine policy and develop joint strategic objectives of the Armed Forces.

Joint Task Force -- A military group established to test the stockpile-to-target sequence of a weapon.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Knot -- A naval unit of speed, equivalent to 1 nautical mile or 6076 feet per hour.

Laydown Device -- A bomb capable of being dropped on a relatively hard target or surface and surviving in a condition to later detonate.

Lenses -- As applied to nuclear weapons, lenses are elements of the high-explosive sphere, which are designed to produce an implosion. The lens charge is composed of high explosives of different burning rates and is so constructed and shaped as to change the explosion initiated by the detonators into an implosive force which converges smoothly on the nuclear materials.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico.

Mach -- A measure of speed. Mach 1.0 is the speed of sound, or 738 miles per hour at sea level.

Matches -- As used in this history, matches are small charges of flammable material that are ignited by an electric spark. The flammable material heats up the solid electrolyte in the thermal battery, and places the battery in operating condition.

Megaton -- A measure of yield of a large weapon. One megaton is the equivalent of 1,000,000 tons of high explosive.

Microsecond -- One millionth of a second.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense Committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

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One-Point Safety Test -- A test in which the high-explosive sphere is detonated at one detonator or point. If the device is one-point safe, no nuclear yield is produced.

Operation Plumbbob -- See Plumbbob.

Operation Redwing -- See Redwing.

Operation Teapot -- See Teapot.

Operation Wigwam -- See Wigwam.

(b)(1), (b)(3)

Radar -- Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Radar Option -- The option of detonating the weapon by radar, which can be set to trigger the weapon at a given height above the terrain.

Redwing -- A full-scale nuclear series of 17 tests held at the Pacific Proving Grounds from May 4 to July 21, 1956.

Reservoir -- As used in this history, a container for deuterium-tritium boosting gas.

Ring Lenses -- High explosive lenses formed in the shape of a ring to occupy less radial space.

Rotochute -- A device to slow down the rate of descent of a free-fall weapon. Consists of counterrotating propeller blades which absorb energy.

Santa Fe Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with Sandia operations.

Sealed Pit -- A weapon in which all the nuclear components (except the boosting gas, when used) are permanently installed in place. Designed to eliminate the need for inflight nuclear insertion mechanisms.

Services -- The Department of Defense.

Sonar -- A system for locating objects by echo reflection of sound waves from an object.

Special Weapons Development Board -- A joint Sandia-Military board at Sandia Base to provide local guidance on weapons design.

Squib -- A device containing a small powder charge. When detonated, the resulting gas pressure closes a switch or performs a similar action. A light, quick-acting, one-shot device.

Tactical -- Use of a weapon against troops or concentrations of war materiel.

Teapot -- A less-than-full-scale test series held at the Nevada Test Site. Series of 14 tests, starting February 18 and ending May 15, 1955.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Tritium -- The hydrogen isotope of mass number 3.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

(b)(3)

X-Unit -- A device used to provide high voltage to the weapon detonators.

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January 1968

RS 3434/18

Changed to Sandia Lvy authority
Memo 3434 NA (2373), 5/2/68
File No. 3434, 1/2/68 Nancy Smith

HISTORY OF THE XW-35 WARHEAD (U)

SC-M-67-669

SC-M-67-669
DC 18
01/68

Weapon Systems

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Information Research Division, 3434

Redacted Version

Sandia Systematic Declassification Review
RETAIN CLASSIFICATION
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Timetable of XW-35 Events

1/7/52 — Military Liaison Committee requests Division of Military Application to make a feasibility study of a warhead for the ATLAS intercontinental ballistic missile.

(b)(1), (b)(3)

10/20/54 — Division of Military Application requests Los Alamos Scientific Laboratory, University of California Radiation Laboratory, and Sandia to study a suitable warhead design for ATLAS.

1/27/55 — Air Materiel Command requests Sandia to submit proposal for ballistic-missile warhead fuze.

3/1/55 — Sandia proposes two-phase approach to fuze design.

5/3/55 — Air Research and Development Command requests Sandia to proceed with fuze design.

7/55 — Authorization issued for feasibility study of thermonuclear warhead for an intercontinental ballistic missile.

9/9/55 — Sandia notifies Santa Fe Operations Office that the XW-35 Warhead can be produced by the fall of 1959.

11/29/55 — Sandia forwards ATLAS fuze proposal to Air Research and Development Command.

2/28/56 — Military Liaison Committee releases set of military characteristics for a warhead compatible with ATLAS, THOR and JUPITER missiles.

3/1/56 — Military Liaison Committee requests development of above warhead.

(b)(1), (b)(3)

7/18/56 — Albuquerque Operations Office authorizes production of XW-35 for ATLAS, TITAN, THOR and JUPITER missiles.

12/6/56 — Air Research and Development Command requests increase in yield of XW-35.

studies of a suitable warhead for the ATLAS, which had the most severe environment.

(b)(1), (b)(3)

The ATLAS missile had a maximum diameter of 10 feet, length of 75 feet, and blastoff weight of 243,300 pounds. Its booster engines possessed a total thrust of 300,000 pounds, and its sustainer engine a thrust of 60,000 pounds. The TITAN had a maximum diameter of 10 feet, length of 90 feet, and weighed 222,400 pounds. It had the same booster and sustainer engine thrusts. The THOR had a diameter of 8 feet, length of 62-1/2 feet, and gross weight of 110,400 pounds. It had one main engine with a thrust of 150,000 pounds. The JUPITER had a diameter of 8-3/4 feet, length of 58 feet, weight of 105,000 pounds, and the same thrust as the THOR.[5]

Air Materiel Command wrote to Sandia January 27, 1955, referring to Sandia's background in fuzing-system design, and requesting a fuze proposal for a ballistic-missile warhead.[6] Sandia replied March 1, 1955, suggesting a two-phase approach. Phase I would be a study of fuzing techniques and characteristics for a ballistic-missile environment, and Phase II would be development of a specific fuze.[7] Subsequently, Sandia was requested to design a fuze for the ATLAS. This would detonate the warhead at or near the surface of the target, to produce high contamination.[8]

(b)(1), (b)(3)

Accordingly, in July 1955, authorization was issued to study the feasibility of developing a thermonuclear warhead for an intercontinental ballistic missile. Due to the program urgency and the desire for the highest yield possible in a given weight, both Los Alamos and the Radiation Laboratory were requested to participate.

Sandia notified Santa Fe Operations Office September 9, 1955 that warhead designs could be firmed up by late 1957, with flight tests starting in early 1958.

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Subsequently, the military characteristics for the Army's JUPITER warhead were approved by the Military Liaison Committee.

(b)(3)

Maximum yield and minimum weight were desired.[16]

The Division of Military Application was notified June 8, 1956 that early ATLAS and THOR missiles would be compatible with the same nose cone and warhead combination, and it was felt that this assembly could be applied to the TITAN. There was some question that any warhead optimized for the fairly blunt, thick nose being developed for ATLAS and THOR would also be best for the light glass ceramic nose cone of the JUPITER, even assuming that physical size and shape were identical. It was felt that full-scale tests might be required before any clear answer became evident.[17]

(b)(1), (b)(3)

The warhead would be carried by ATLAS,

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TITAN and THOR missiles, and also the JUPITER, if this was possible without compromising the other designs.[19]

(b)(1), (b)(3)

This would provide a warhead for the ATLAS, THOR and JUPITER by their operational dates, and a warhead for TITAN well before its ready date. The University of California Radiation Laboratory would develop the XW-38, a higher yield and heavier warhead, for a later operational date.[20]

A composite warhead configuration was evolved to allow use of either the 20-inch-diameter XW-35 or the larger XW-38 with a common mounting flange. In the ATLAS and THOR nose cones, arming and fuzing components and attitude-control mechanism would be mounted in the annular space around the warhead. In the TITAN nose cone, the warhead would be mounted close to the front face, and this might involve heating problems. It would also have to be determined that weapon detonation would occur prior to nose deformation in contact bursts.[3]

The ATLAS, THOR and TITAN nose cones used copper heat sinks to distribute the heat throughout the nose-cone metal, which was expected to attain a temperature of about 1700°F. The JUPITER nose cone would be coated with a layer of fiberglass which would partially burn off during re-entry. This would physically remove heated material and it was hoped that the insulating properties of the fiberglass would help to keep the warhead compartment cool.[3]

Since it was felt that an antiballistic missile system might be in operation by 1960, the scheduled operational date for most of the missiles, it was desired that the warhead be made radiation-insensitive. This precluded use of transistors, diodes and similar devices. The warhead would be sealed and require a minimum of field testing. Monitoring would be accomplished through nose cone and missile consoles.[3]

The entire firing system would be potted, for adaptability to reduced pressures at high altitudes. The system would require three arming signals and either

October 1958. The warhead would be contained inside the nose cone, which would separate from the rest of the missile about 5 minutes after launch and then proceed along a ballistic trajectory to the impact point. Fuzing operations would occur upon re-entry into the atmosphere.[24]

The Assistant Secretary of Defense wrote to the Atomic Energy Commission March 29, 1957, noting that it was important that the ATLAS warhead yield be as large as possible within the prescribed weight limitations.

(b)(1), (b)(3)

The October 1958 operational availability date was to be retained at all costs.[25]

Report SC3995(TR), Proposed Ordnance Characteristics of the XW-35 Warhead, was discussed in the April 24, 1957 meeting of the Special Weapons Development Board.[26] The report proposed that a two-phase program be followed to provide a 20-inch version of the XW-35 for early operational capability and a higher yield version at a later date.[5] With the understanding that the XW-35 Mod 0 would be provided for initial use, the report was approved and forwarded to the Division of Military Application July 11, 1957.[27]

(b)(1), (b)(3)

the components.

(b)(3)

The main case and aft section would be sealed and pressurized to provide environmental protection during storage and operation. The firing system would be tested and certified at time of manufacture, and the warhead would require only continuity and pressure testing in the field or stockpile. There would be no field replacement of components and no need to break the warhead seal while the weapon was in military custody. The warhead would be provided with desiccant at the time of assembly to assure a low moisture content.

(b)(3)

Some suggestions had previously been made that emergency-capability warheads be provided. Thus, November 8, 1956, the Division of Military Application notified Albuquerque Operations Office that, as a result of a series of successful JUPITER tests, the Army was considering acceleration of this missile program.[31] Some attention was subsequently given to use of either XW-28 or XW-35.[32]

The same request was made, February 19, 1957, on behalf of the THOR.[33] Later, in August 1957, the JUPITER warhead emergency-capability program was cancelled.[34] However, December 2, 1957, the Military Liaison Committee noted that the Department of Defense was again accelerating the intermediate-range ballistic missile program. Both THOR and JUPITER squadrons, each requiring 15 missiles, would be operational by late 1958.

(b)(3)

In May 1958 it was decided that emergency-capability warheads for intermediate-range ballistic missiles would be supplied by XW-49 Warheads, which were

XW-28-Y1's modified to suit size and weight requirements. The emergency-capability units for the intercontinental ballistic missiles would be hand-built models of the XW-35-X1 and would be available by April 1959.[36]

Sandia wrote to the Division of Military Application May 5, 1958, nothing that considerable concern had been expressed over the safety of sealed-pit warheads.

(b)(3), (b)(1)

It had been suggested that an environmental sensing device be incorporated in the warhead electrical system to prevent detonation by any chance application of the sequence of electrical input signals. Study was being made of a single device that could be used with both missiles and bombs. The nose-cone re-entry deceleration formed a unique and common environment experienced prior to weapon detonation, and it was proposed that this deceleration pulse be used to close an inertial switch.

In the XW-35-X1 system, assembly of two such switches would be cross-connected and potted into a firing-set package. Production tests through warhead acceptance level would be accomplished by actuating the inertial switches on a centrifuge that would duplicate the re-entry environment, and electrical resets would be provided to return the switches to the safe position.[37]

(b)(1), (b)(3)

Pit -- The hollow metal sphere at the center of an implosion bomb which receives the nuclear capsule when it is inserted.

Plumbbob -- A less-than-full-scale test series conducted at the Nevada Test Site. Series of 29 tests, starting May 28 and ending October 7, 1957.

Potting -- A means for improving the shock resistance of any item by embedding it in a plastic compound.

Primary -- A fission bomb that acts as the source of emergy to start the secondary, or thermonuclear, reaction of a two-stage bomb.

Proton -- The nucleus of the atom of the light isotope of hydrogen. It has a unit positive charge of electricity.

Redwing -- A full-scale test series held at the Pacific Proving Grounds. Series of 17 tests, starting May 4 and ending July 21, 1956.

Re-entry Shock -- The shock produced when a missile re-enters the earth's atmosphere.

(b)(1), (b)(3)

Timetable of Mk 38 Events

(b)(1), (b)(3)

7/55 Study shows that design is feasible. Authorization issued to Los Alamos Scientific Laboratory and University of California Radiation Laboratory to proceed with parallel designs.

1/19/56 Nomenclature of XW-38 assigned to the Radiation Laboratory design.

3/56 Design expanded to include the TITAN intercontinental ballistic missile and the THOR and JUPITER intermediate-range ballistic missiles.

(b)(1), (b)(3)

7/18/56 Full-scale development of XW-38 Warhead authorized by Albuquerque Operations Office.

11/26/56 Division of Military Application changes design of XW-38 to a 3000-pound warhead, to be provided on a low-priority basis as a follow-on to the Los Alamos XW-35.

5/27/57 Assistant Secretary of Defense requests study of high-yield warhead for carriage by intercontinental ballistic missiles.

(b)(1), (b)(3)

5/7/58 Assistant Secretary of Defense requests feasibility study of high-yield warhead for ATLAS and TITAN.

(b)(1), (b)(3)

(b)(1), (b)(3)

3/11/59	Designation of XW-35-X1 assigned to high-yield XW-38 Warhead.
5/13/59	Amendment to the military characteristics deletes the requirement for compatibility of the XW-38-X1 with the THOR and JUPITER missiles.
11/59	Production authorization for XW-38-X1 issued.

(b)(1), (b)(3)

5/61	First unit of Mk 38 Warhead produced.
8/18/61	Report SC4825(WD), Mk 38 Mod 0 Status at Design Release, forwarded to the Division of Military Application.
6/63	Report SC4825(WD), Final Development Report for the Mk 38 Mod 0 Warhead, forwarded to the Division of Military Application.
Mid-1965	Mk 38 Warheads retired.

(b)(1), (b)(3)

The Assistant Secretary of Defense wrote to the Atomic Energy Commission, May 7, 1958, noting that the Joint Chiefs of Staff had approved an operational requirement for a high-yield warhead to be carried by intercontinental ballistic missiles. This weapon was to attack targets that required heavier payloads than the XW-35. The warhead would be designed for the ATLAS and TITAN, and it was hoped that it would be compatible with intermediate-range ballistic missiles. The warhead could weigh as much as 3500 pounds, have maximum yield for this weight, and was operationally desired by 1962.[13]

(b)(1), (b)(3)

The fuzing and firing components, ~~parachute and afterbody~~ would be contained in a cylindrical space 34 inches in diameter and 24 inches long.

(b)(3)

(b)(1), (b)(3)

Thus, the Department of Defense had authorized the development of such a weapon for application to the ATLAS, TITAN, THOR and JUPITER missiles. The warhead would be operationally available in mid-1961, and the Air Force was designated

cognizant agent for the Department of Defense portion of the program, with normal Armed Forces Special Weapons Project participation.[15]

A set of military characteristics was approved by the Military Liaison Committee January 20, 1959.[16]

(b)(1), (b)(3)

The warhead would be capable of becoming electrically armed within 5 seconds of receipt of the arming signal and remaining in this condition for at least 90 seconds, and would fire upon receipt of either air-burst or contact-burst signals. If, when armed, electrical energy was stored in the warhead awaiting the firing signal, a device would be incorporated to safely dissipate the electrical energy in the shortest time possible, not to exceed 10 minutes and not to interfere with the normal arming-firing sequence.

The warhead would not contain any primary source of energy. No final assembly procedures would be necessary after delivery of the warhead to the Military. Assembly of warhead to missile re-entry body would be as simple, quick and safe as possible, and require a minimum amount of specialized equipment and personnel.

At least one arming device, which would also serve as a safety device, was required to sense the unique environment of the missile after launch and before warhead operation. This device would be installed in a manner to minimize the possibility of nuclear detonation through sabotage. The design priorities emphasized safety from nuclear disaster to friendly installations, weapon reliability, operational simplicity, and ease of maintenance.[17]

(b)(1), (b)(3)

Sandia would have full responsibility for warhead design, except for nuclear materials and components.[18] A designation of XW-38-X1 was assigned to the program to distinguish it from the initial aims of the XW-38 project.[19]

(b)(1), (b)(3)

(b)(3) A production date of May 1961 would be required to meet the June 1961 operational availability date. These dates would require expediting the program to the utmost, and no delays could be tolerated in the missile flight-test program.

The Department of Defense agency responsible for the missile systems was the Air Force Ballistic Missile Division. Systems contractor for the Military was the Space Technology Laboratory, Inglewood, California. The Research and Advanced Development Division of Avco Manufacturing Corporation, Wilmington, Massachusetts, was the subcontractor for re-entry vehicle design and development. Avco would also provide arming and fuzing system design.

Warhead responsibility was divided between Lawrence Radiation Laboratory and Sandia's Livermore Laboratory. Lawrence was responsible for the nuclear functioning of the warhead and the design and production specifications of all nuclear components and materials. Sandia had responsibility for the design and production specifications of the remaining warhead components and materials.

Flight tests aboard TITAN were scheduled to start in March 1960, and a total of 16 flights were required to obtain necessary warhead environmental and systems operational data. A minimum of three successful warhead flight tests on the ATLAS missile were desired. Design release of the warhead was scheduled for August 1960.

There were three basic firing systems under consideration. One included explosive ferroelectric external initiators, an explosive ferromagnetic X-unit, and acceleration-sensing handling-safety devices. Another proposal featured an electronic external initiator, capacitor-type X-unit, chopper-converter system, trigger circuit, and acceleration-sensing handling safety devices. The third scheme had a Jonah initiation system, explosive ferromagnetic X-unit, and acceleration-sensing handling safety devices. The warhead would be sealed and require only continuity monitoring in stockpile or field.

The ATLAS was a 1-1/2-stage intercontinental ballistic missile 10 feet in diameter and 80 feet long. It was classed as a 1-1/2-stage missile because the two booster engines drew their fuel from the main missile tanks; the engines separated at the

end of the boost phase, but the tanks remained with the missile to supply fuel for the sustainer engine. The ATLAS weighed 269,000 pounds at takeoff, of which about 252,000 pounds was liquid oxygen and fuel for the rocket motors. The maximum range of the ATLAS was in excess of 5500 nautical miles, and it attained a speed of 23,500 feet per second (16,000 miles per hour). The booster engines each developed 165,000 pounds of thrust, and the sustainer engine 67,000 pounds. Final position and velocity adjustments for the missile were made by two small vernier rockets. After these vernier rockets stopped firing, the re-entry vehicle separated from the missile and followed a ballistic trajectory to the target.

The TITAN was a 2-stage intercontinental ballistic missile with a maximum range in excess of 5500 nautical miles. It was 10 feet in diameter, 97 feet long, and weighed 221,000 pounds at takeoff, of which about 200,000 pounds was liquid oxygen and fuel. The first-stage booster, which developed 300,000 pounds of thrust, separated from the rest of the missile at booster-engine cutoff, carrying with it all associated tankage, plumbing and controls. The second stage, or sustainer, then fired, developing 80,000 pounds of thrust. At sustainer-engine cutoff, vernier rockets made a final velocity correction. The re-entry vehicle then separated from the missile and followed a ballistic path to the target.

(b)(1), (b)(3)

(b)(1), (b)(3)

An amendment to the military characteristics was approved by the Military Liaison Committee May 13, 1959. This amendment deleted the requirement for compatibility of the XW-38-X1 Warhead with the THOR and JUPITER intermediate range ballistic missiles.[2]

Sandia wrote to Albuquerque Operations Office September 29, 1959, recommending that XW-38-X1 production units be identified as Mk 38 Mod 0 Warheads. Since advance ordering information was being provided to meet the accelerated production schedule, it was felt that production nomenclature should be assigned, and this suggestion was subsequently accepted.[22,23] Production authorization for the warhead was issued in November 1959.

(b)(1), (b)(3)

The Division of Military Application, in a teletype of June 10, 1960, suggested that the XW-38-X1 be assigned a high priority, in an effort to retain the early production date of May 1961.[25] Sandia and Lawrence issued a joint reply, June 30, 1960, stating that the program status did not warrant release of material for operational use.[26] Despite this, however, the project was authorized use of extra funds, and calculated risks in early assembly were taken.

(b)(1), (b)(3)

Early production units of the Mk 38 Warhead began to flow from the assembly lines in May 1961.

The ablative heat shield was constructed of fiberglass covered with oblique tape-wound fibrous quartz.

An integrating inertial switch was provided, with two sets of normally open contacts, which interrupted input lines from the adaption kit to the warhead arming components. This switch prevented arming until the warhead experienced an acceleration environment of powered flight. The switch contacts closed when the warhead had undergone a minimum acceleration of 3.5 g's and an acceleration-time product of at least 15 g-seconds. The switch would not operate under an acceleration of 2 g's or less, regardless of how long this acceleration was applied. Accelerations greater than 10 g's were clipped, ensuring that momentary applications of very high accelerations would not close the switch.

(b)(1), (b)(3)

(b)(1), (b)(3)

The firing set contained a dual-channel chopper-converter, a single-channel capacitor X-unit, and a tack switch. This assembly received 28 volts direct current from the adaption kit and converted this to alternating current, which was transformed into two higher voltages, rectified separately and supplied to the X-unit

When the missile attained the position and velocity necessary for the re-entry vehicle to reach its target, a guidance prearm signal from the missile passed through a lockout switch.

(b)(1), (b)(3)

A separation signal from the missile then passed through the lockout switch and operated the missile/re-entry vehicle separation mechanism. The re-entry vehicle separated from the missile and followed a ballistic path to the target.

(b)(1), (b)(3)

When the re-entry vehicle entered the atmosphere, it righted itself and started to decelerate. This deceleration activated the arming-firing battery in the adaption kit. When this battery came up to voltage, it supplied power through environmental sensing devices to the chopper-converter motors.

(b)(1), (b)(3)

If air burst had been selected, the air-burst switch operated at the selected altitude, sending a firing signal through the air-ground relay to the tack switch. This switch transferred energy from the X-unit capacitor to the warhead detonators and triggered the neutron generators. If ground burst had been selected, or if the air-burst switch failed, impact detectors in the nose of the re-entry vehicle were actuated by the ground impact. These detectors triggered a signal that fired the tack switch.

The design-release report was presented to the Design Review and Acceptance Group of Field Command. It was noted that the design met all requirements of the approved military characteristics, with the following exceptions: The warhead length had been increased to 82.45 inches, but this was at the request of the using Service for convenience in adapting the warhead to the re-entry vehicle, and was acceptable.

An increase in weight to 3080 pounds was acceptable in view of a mutually agreed-upon upper limit of 3130 pounds.

(b)(1), (b)(3)

The overall design was thus felt to be acceptable to the Department of Defense, and Report SC4825(WD) was forwarded to the Division of Military Application August 18, 1961.[28]

Report SC4842(WD), Final Development Report for the Mk 38 Mod 0 Warhead, was released in June 1963.[29] Flight testing had been initially delayed to incorporate components fully representative of War Reserve items and again postponed due to nonavailability of missiles. Thus the flight tests, which had been originally scheduled for completion in early 1961, were not finished until December 1962.

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Albuquerque Operations Office issued notice December 11, 1964, that the Division of Military Application had decided to retire the Mk 38 Warhead by mid-1965. Sandia was requested to cancel any further design changes.[30]

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Kilogram -- A metric weight approximating 2.2 pounds.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Lawrence Radiation Laboratory -- A change of name for the University of California Radiation Laboratory (which see), effective October 1958.

Lenses -- As applied to nuclear weapons, lenses are elements of the high-explosive sphere, which are designed to produce an implosion. The lens charge is composed of high explosives of different burning rates and is so constructed and shaped as to change the explosion initiated by the detonators into an implosive force which converges smoothly on the nuclear materials.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico.

Megaton -- A measure of yield of a large weapon. One megaton is the equivalent of 1,000,000 tons of high explosive.

Microsecond -- One millionth of a second.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

(b)(1), (b)(3)

Operation Hardtack -- See Hardtack.

Operation Plumbbob -- See Plumbbob.

Operation Redwing -- See Redwing.

AEC ATLANTA AUSTRALIA

Pit -- The hollow metal sphere at the center of an implosion bomb which receives the nuclear capsule when it is inserted.

Plumbbob -- A less-than-full-scale test series held at the Nevada Test Site. Series of 29 tests, starting May 28 and ending October 7, 1957.

Primary -- A fission bomb that acts as the source of energy to start the secondary or thermonuclear reaction of a two-stage device.

Proton -- The nucleus of the atom of the light isotope of hydrogen. It has a unit positive charge of electricity.

Redwing -- A full-scale nuclear series of 17 tests held at the Pacific Proving Grounds from May 4 to July 21, 1956.

Re-entry Vehicle -- That part of a ballistic missile that forms the nose of the missile, generally contains the warhead, and is detached from the missile during the trajectory to re-enter the earth's atmosphere and follow a ballistic trajectory toward the target.

Reservoir -- As used in this history, a container for deuterium-tritium boosting gas.

Santa Fe Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with Sandia operations.

Secondary -- The thermonuclear portion of a two-stage weapon.

Services -- The Department of Defense.

Squib -- A device containing a small powder charge. When detonated, the resulting gas pressure closes a switch or performs a similar action. A light, quick-acting, one-shot device.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

Ton (Yield) -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-ton yield is equivalent to the detonation effect of 2000 pounds of high explosive.

Tritium -- The hydrogen isotope of mass number 3.

Two-Stage -- Combination of fission and fusion action in a weapon.

University of California Radiation Laboratory -- A laboratory established at Livermore, California. Initially founded for work on the thermonuclear designs.

AUSTRALIA ATLANTA AEC

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

Warhead -- A weapon carried to the target by missile.

X-Unit -- A device used to provide high voltage to the weapon detonators.

References

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(b)(1), (b)(3)

2. SRD Report, RS 8233/1151, Sandia Corporation to Distribution, dtd 4/60, subject, Report SCDR-57-59, Development Record of the XW-38-X1 Warhead. SC Reports Files.

3. SRD Case, RS 7221/577, Sandia Corporation to Distribution, dtd 8/9/57, subject, Design and Development of the XW-38 Warhead. SC Central Technical Files, XW-38, 1.1, Authorization.

4.

5.

(b)(3)

6.

7. SRD Ltr, University of California Radiation Laboratory to Distribution, dtd 9/19/56, subject, UCRL Participation in Warhead Development for ICBM/IRBM. AEC Files, MRA-5, XW-35 to 38, 7/56.

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9. SRD Ltr, RS 3466/82672, Albuquerque Operations Office to Distribution, dtd 3/5/57, subject, XW-38 Warhead. SC Central Technical Files, 38 Program, 2-, 1956-63.

10. SRD Ltr, Assistant Secretary of Defense to U. S. Atomic Energy Commission, dtd 5/27/57. AEC Files, MRA-5, Warhead, 7/56-6/57.

11. SRD Ltr, Division of Military Application to San Francisco and Albuquerque Operations Offices, dtd 6/12/57, subject, Feasibility Study of 2600 Pound ICBM Warhead. AEC Files, MRA-5, Warhead, 7/56-6/57.

12.

(b)(3)

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January 1968

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HISTORY OF THE MK 39 WEAPON (U)

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RS-3434/ 20
01/68

Weapon Systems

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CARRIERS

1 B-58 POD
2 SM-62 SNARK
3 REDSTONE

MK 39 MOD 1 WARHEAD

LENGTH 104.5 IN.
DIAM. 34.5 IN.
WEIGHT 6230 LBS.

Mk 39 Mod 1 Warhead

Timetable of Mk 39 Events

Mk 39 Mod 0 Bomb

11/22/55 Military Liaison Committee requests that new weapon designation be assigned to modification of the Mk 15 and TX-29.

4/25/56 Sandia presents status at design release of the Mk 39 Mod 0 to meeting of Special Weapons Development Board.

(b)(1), (b)(3)

3/20/57 Sandia presents final engineering evaluation report of the Mk 39 Mod 0 Bomb to meeting of Special Weapons Development Board.

Mk 39 Mod 1 Weapon

1/16/56 TX/XW-15-X3 modification redesignated TX/XW-39-X1 program, with new primary and reduced weapon weight.

2/29/56 Sandia presents proposed ordnance characteristics of new design to meeting of Special Weapons Development Board.

(b)(1), (b)(3)

3/57 Sandia releases status at design release of the TX/XW-39-X1.

(b)(1), (b)(3)

8/20/58 Sandia presents final evaluation of Mk 39 Mod 1 Bomb/Warhead to meeting of Special Weapons Development Board.

(b)(1), (b)(3)

Mk 39 Mod 2 Bomb

9/17/56 Field Command requests Sandia to study feasibility of a laydown Mk 39 Bomb.

11/18/57 Air Force notifies Division of Military Application that Strategic Air Command has urgent requirement for a low-altitude laydown Mk 39. Design named the Big Tail.

(b)(1), (b)(3)

When the bomb fell a sufficient distance, the pressure switch closed. When open, this switch isolated the low-voltage power supply from the coils of the high-voltage safing switch. When closed, power from the low-voltage battery pack operated the high-voltage safing switch, completing the circuit between the high-voltage power supply and the X-unit. At arming altitude, the arming baroswitch closed and connected the 28-volt power supply, through two fuses, to the primaries of two high-voltage thermal-battery ignition transformers. The pulse from the transformer secondaries activated the high-voltage power supply and the two fuses blew in approximately 100 milliseconds and removed this high current load from the low-voltage power supply. The high-voltage power supply charged the X-unit to 2500 volts and supplied this voltage to the trigger circuit.

At air-burst firing altitude, the baroswitch closed, connecting the 28-volt power supply, through two fuses, to saturable transformers in the trigger circuit. The two fuses blew in approximately 100 milliseconds and removed this high current load from the power supply. In the air-burst option, the saturable transformers passed the fire signal, firing the trigger circuit, X-unit, and the weapon. In the contact option, the saturable transformers blocked the fire signal, and the weapon was detonated by a signal from the contact fuzing system.[23]

The drop-test program for the bomb consisted of 28 drops, 8 of which were ballistic and 20 were fuzing and firing tests. These proved compatibility with the bomb, parachute system, and carriers. The fuzing and firing drops covered a wide range of speeds and altitudes, with about half the drops being free fall and the other half retarded.

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AEC ATOMIC WEAPON DATA

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HISTORY OF THE MK 40 WARHEAD (U)

SC-M-67-672

Weapon Systems

SC-M-670672

01/68

Redacted Version

Information Research Division, 3434

RESTRICTED DATA

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Classification Analyst, Org 4225
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Sandia Systematic Declassification Review
RETAIN CLASSIFICATION
B.J. Duff 2/11/97

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had been proposed, including the Mks 7, 12 and 30, but it was felt that they were too heavy for their yield.[2]

However, as missile design became more firm, the Air Force Special Weapons Center notified Sandia, December 12, 1955, that the missile would become operationally available July 1, 1959. It was felt that the warhead compartment of the BOMARC would be able to carry an atomic device with a diameter of 18 inches, and that space should be available for X-unit, gas-boosting equipment, and external initiator.

(b)(1), (b)(3)

Sandia replied December 28, 1955, stating that a 17-inch-diameter warhead could be developed, which would have a weight less than 300 pounds and the desired yield, and be able to survive the BOMARC's launching boost and cruising speed.

(b)(1), (b)(3)

Another missile came under consideration January 26, 1956, when the Assistant Secretary of Defense wrote to the U. S. Atomic Energy Commission, noting that the Army was developing the LACROSSE missile and hoped to achieve an atomic capability.[5] The LACROSSE had a 20.5-inch-diameter body which was 19 feet long and weighed 2350 pounds at launch. It had a wingspan of 9 feet, two main swept-back wings, and a 4-fin tail. The initial launching boost, as well as flight power, was provided by a solid-fuel rocket which produced a missile speed of Mach 1.5.

The LACROSSE was a surface-to-surface missile designed for precision delivery against land targets under direct observation in close support situations. The missile was launched from a 2-1/2-ton Army truck located from 8,000 to 30,000 meters from the target (5 to 18.5 miles). The missile was launched in the general direction of the target and flew at altitudes between 5,000 and 13,000 feet above the launching point. It was acquired in flight by a jeep-transported forward guidance station and guided to the target by radio and optical techniques.

(b)(1), (b)(3)

A feasibility study of possible warheads for the LACROSSE missile was completed by Sandia and forwarded to Albuquerque Operations Office June 6, 1956.

(b)(1), (b)(3)

Both these warheads could be made available by April 1959.[11]

By mid-1956 the design of the XW-40 Warhead was taking shape. The warhead would be sealed and gas-boosted. The warhead electrical system was practically identical with the Mk 28 system, and used the same X-unit, removable high-voltage battery pack, dual external initiators, dual motor-operated arm/safe switches, gas-boosting mechanism, and dual cold-cathode thyratron trigger circuits.

(b)(3), (b)(1)

The warhead diameter would be slightly larger than desired, 17.9 inches, and the length would be 31.56 inches. It was expected that the weight could be held to 290 pounds. Only minor maintenance would be permitted in the field, since assembly or disassembly of the sealed warhead would require special tools. Positive safing during storage and handling was provided by removable batteries. The warhead would be pressurized with dry air or nitrogen.[13]

(b)(1), (b)(3)

(b)(1), (b)(3)

The Army's Picatinny Arsenal had advocated that interface problems on the XW-40/LACROSSE be handled by the concerned project officers, rather than through a special joint committee, as had been the custom for previous weapons. It was suggested that the participating agencies each appoint a representative; with Sandia being responsible for the warhead, the Army responsible for the rest of the missile-warhead system, and the Armed Forces Special Weapons Project responsible for the interests of other military services.[17] This proposal was adopted.[18]

A third missile program was introduced when the Assistant Secretary of Defense wrote to the Atomic Energy Commission, September 19, 1956, requesting cooperation with the Navy in the feasibility study of a nuclear warhead for the CORVUS missile.[19] The CORVUS was an antiship, air-launched missile designed to home-in on enemy radar installations. The CORVUS was scheduled to be operationally deployed for evaluation in mid-1960, with delivery to the Fleet in April 1961. The missile would be carried by AD4-, A3D-, and P6M-type aircraft, which would launch the missile from a maximum standoff range of about 170 nautical miles.[20]

A working group was established, and Sandia studied the physical fit of several nuclear warhead designs in the CORVUS.[21] There were some warheads that could be

modified for such installation, but none met all the requirements established by the Navy Bureau of Aeronautics.

(b)(1), (b)(3)

An XW-40/CORVUS could be provided which would meet most of the Navy requirements, but modification of warhead case and missile compartment would be necessary. It was felt that this redesign might delay the release date of the warhead, currently estimated as January 1958, and affect its application to the BOMARC and LACROSSE.[22]

Work had meanwhile been proceeding on the design of the XW-40 Warhead. The high-voltage battery package would contain five batteries connected in series, with a pair of silicon diodes shunted across each set of battery terminals to allow normal operation of the other four batteries, should one unit fail. Thermal fuses would be located in the ground line to isolate the battery output in the event of fire. Dual squib transformers would be provided to minimize power requirements and to provide increased reliability and reduced size. The high-voltage arm/safe switches would be motor-driven and reversible, thus affording positive control. These switches were inherently fire-safe and could not be inadvertently operated by electromagnetic radiation.

The gap switch of the XW-40 could be fired by either of two methods. One was by a low-impedance source, provided by the adaption kit, with signals derived from timers, impact switches, or barometric switches. The other was by a high-impedance source, such as supplied by radar, thyratrons or contact crystals. This required the design of a 4-probe gap and four pulse-type firing transformers; two for the low-impedance and two for the high-impedance signals.

The use of the warhead in the air-defense BOMARC made it mandatory that the warhead components have low sensitivity to nuclear radiation.

(b)(3)

(b)(3)

Components that were squib-initiated or explosively operated were also sensitive to electromagnetic radiation and discharges of static electricity.[6]

Sandia notified Albuquerque Operations Office, February 5, 1957, that no approved military characteristics had been received for the XW-40 Warhead. It was estimated that flight tests of the warhead in both the BOMARC and LACROSSE would start by May 1957, with 15 flights being required to provide necessary environmental and systems operational data. The first squadron of BOMARC and LACROSSE missiles would not become operational until mid-1959, although the warhead would undoubtedly be available by this time.[23]

The Division of Military Application wrote to Albuquerque Operations Office March 6, 1957, noting that the operational availability date of the XW-40 Warhead had apparently slipped from January to July 1959, and requesting an explanation of the delay.[24] Albuquerque Operations referred the request to Sandia, noting that, if at all possible, the earlier date should be maintained. It was felt that warhead availability should not be tied to the date on which a missile squadron became operational.[25]

Sandia replied, April 10, 1957, that the latest flight-test schedule dates meant that the six required systems tests of the XW-40 Warhead in the BOMARC and LACROSSE missiles would not be completed until some time after January 1958. It was felt that at least nine missile flights would be required to provide six successful tests. Thus, a design-release date of July 1958 for the warhead and an operational-availability date of mid-1959 appeared to be logical.

(b)(1), (b)(3)

(b)(1), (b)(3)

Picatinny Arsenal had requested Sandia to prepare a contract covering flight-test telemetering and use of Sandia's sled track for contact-fuze tests of the XW-40/LACROSSE program. This contract was submitted to Albuquerque Operations Office April 12, 1957, and subsequently put into effect.[27] It had been decided that interface problems of the XW-40/BOMARC program would also be handled on a project-officer basis.[28]

(b)(1), (b)(3)

Approved military characteristics for the XW-40 Warhead were released by the Military Liaison Committee June 18, 1957. Warhead applications included BOMARC and LACROSSE missiles, as well as other applications that might be authorized by the Department of Defense. The parameters of the warhead would be held to a practicable minimum and would not exceed a diameter of 17.4 inches, length of 31.7 inches, and a weight of 300 pounds.

(b)(1), (b)(3)

Preliminary investigation had indicated the feasibility of incorporating such high-yield warheads in the BOMARC missile, and a study was requested.[30]

(b)(1), (b)(3)

Either design could be made operationally available by January 1962 without interference with existing work.[31] The project was subsequently canceled April 22, 1958, as it was felt that the XW-47 Warhead then being designed for the POLARIS missile would better satisfy the requirements.[32]

Sandia presented Report SC4071(TR), Proposed Ordnance Characteristics for the XW-40 Warhead, to the August 21, 1957 meeting of the Special Weapons Development Board.[33]

(b)(1), (b)(3)

The Board accepted the report and it was subsequently forwarded to the Division of Military Application.[35]

(b)(1), (b)(3)

The Assistant Secretary of Defense wrote to the Atomic Energy Commission November 13, 1957, noting that a joint feasibility study for a nuclear warhead for the CORVUS missile had been completed. The study had concluded that the XW-40 Warhead could be applied to the missile without change, and it was requested that design of the project be instituted, in cooperation with the Navy.[36]

Meanwhile, it had been decided that the BOMARC adaption kit would be provided by the Air Force. This kit would contain an arming and fuzing system, external power supply, and most of the self-destruct system. The safing and arming device was a limited integrating accelerometer. The kit contained an arming program that sequenced the input signals to the warhead and fuze.

The warhead would normally be detonated by its primary fuze, an electronic influence device. A secondary predictor-computer-type fuze would receive information from a target seeker and provide backup if the target did not come within firing range of the primary fuze.

(b)(3)

Boeing Airplane Company was supplying the adaption kit, and the Diamond Ordnance Fuze Laboratory was developing the arming and fuzing system.[1]

Field Command noted that the failure probability of 1 to 130 for the self-destruct system was far short of the 1 to 10,000 required by the military characteristics.[37] Sandia replied, February 12, 1958, stating that the warhead design was well along when the approved military characteristics were released, and that any appreciable gain in reliability could only be achieved through the use of dual systems. This would lengthen the warhead by 3 inches, increase its weight by 5 pounds, and require 6 months' additional development time. Since both BOMARC and LACROSSE missiles used ~~in~~ a single-channel self-destruct system, it appeared that this signal derivation could not approach the reliability requested.[38]

The Division of Military Application sent a teletype to the Albuquerque Operations Office March 31, 1958. Recent information had indicated an activation date of October 1959 for the first LACROSSE squadron, and it therefore appeared that a warhead operational availability date of July 1959 would be suitable.[39]

(b)(1), (b)(3)

agency was the Navy Bureau of Aeronautics, with the Bureau of Ordnance assisting in problems of fuzing, arming, self-destruction and warhead-missile compatibility.[50]

The Mk 40 Warhead was released for use in the BOMARC and LACROSSE June 30, 1959, and early production of the warhead occurred September 1959. Report SC4189(TR), Status at Complete Design Release and a Final Engineering Evaluation of the XW-40 Warhead,[51] was presented to the October 21, 1959 meeting of the Special Weapons Development Board. The warhead was 17.9 inches in diameter, 31.5 inches in length, and weighed 304 pounds. (b)(1), (b)(3)

The Board accepted the report for forwarding to the Division of Military Application.[53]

(b)(1), (b)(3)

(b)(1), (b)(3)

Normally, such a change would have required a new Mod number of the warhead. However, since only a few items had been produced, it was felt that adequate control could be maintained by serial number until all the warheads had been properly retrofitted.[54]

At this time, a proposal was made to incorporate an environmental safing device to provide increased safety in handling the Mk 40 Warhead. This device would be operated by the acceleration experienced by the warhead in the boost phase of the missile flight, and the Services were requested to provide the appropriate longitudinal accelerations.[55]

Sandia wrote to Field Command March 28, 1960, discussing current progress in the self-destruct system.

(b)(1), (b)(3)

To satisfy the military characteristics, development work had been started on a dual-channel charging and triggering circuit, but it was evident that these improved units would not become available until a substantial number of the Mk 40 Warheads had entered stockpile.

(b)(1), (b)(3)

Transistor production difficulties had delayed the firing sets,

action link or arming-control device to be incorporated into the LACROSSE application for an additional measure of command control. This would have created the Mk 40 Mod 3.[67] Subsequently, Albuquerque Operations Office sent a teletype to Sandia April 10, 1963, stating that the Division of Military Application had ordered suspension of activity on the Mk 40 Mod 1 and Mod 3 for LACROSSE, applying both to the environmental sensing device and prescribed action link.[68] Eventually, a few Mod 1's were produced and stockpiled in August 1964, but they were withdrawn several months later.

Design work continued on the Mk 40 Mod 2 for the BOMARC application.[69] A ground compatibility test was held, which disclosed electrical feedback through missile wiring from one motor-driven arm/safe switch to the other when the motor speeds were sufficiently different. This feedback caused a cyclic condition that caused the switches in some warheads and missiles to run abnormally long before stopping at their proper positions. Due to a difference in wiring, this problem applied only to the XM-99A or early BOMARC design.[70]

Sandia studied the situation and reported, May 27, 1963, that modification of the Mk 40 Warhead did not appear to be warranted, as the switch cycling was not caused by any warhead defect. It was pointed out that peacetime nuclear safety was not lowered, and that the total effect of the cycling on warhead safety was minor. The condition was dependent on the missile's being launched, the warhead's being fully armed, a failure of the system to detonate the warhead, and a failure of the self-destruction system. It was noted that, if all these events occurred, and the arm/safe switch failed to return to safe for any reason, including cycling, some nuclear yield might be produced when the warhead impacted the ground. It was suggested that warheads in stockpile be tested and that defective units be replaced.[71]

Mk 40 Mod 2 retrofit kits were subsequently stockpiled in December 1963 for use with the BOMARC missile.

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January 1968

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AEC ATOMIC WEAPON DATA
Sigma X

HISTORY OF THE MK 41 WEAPON (U)

SC-M-67-673

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The Radiation Laboratory would have responsibility for nuclear components, and Sandia would be responsible for nonnuclear components. Project responsibility would rest with Sandia-Livermore, with Sandia-Albuquerque furnishing assistance on such items as nose fairing, afterbody, fins and fuzing system.

The weapon would have a diameter of 50 inches, warhead length of 120 inches and weight of 9300 pounds, and bomb length of 145 inches and weight of 10,000 pounds. The high-voltage power supply would be removable, but otherwise the entire weapon would be sealed, and the fuzing and firing system tested as a go/no-go assembly. Warhead fuzing would be provided by the missile contractor.

(b)(1), (b)(3)

Sandia wrote to the Air Force Special Weapons Center April 17, 1957, suggesting that a joint working group be formed to consider problems relating to the XW-41/NAVAHO.[16] A similar letter, dated April 22, 1957, requested the support of the 4925th Test Group (Atomic) in the bomb drop-test program. This program would prove out the fuzing and firing system and determine ballistic performance, and the series would consist of 42 drops, half of which would be parachute-retarded. Drops would start in November 1957, proceed at the rate of two or three per month, and be completed in early 1959. Releases would be made from B-47 and B-52 aircraft, flying at speeds of Mach 0.75 to 0.9 and at altitudes between 20,000 and 55,000 feet. About half the tests would be made over water and half over land, with the facilities of both Salton Sea Test Base and Tonopah Test Range being used.[17]

The Radiation Laboratory notified the Division of Military Application April 29, 1957 that there was a serious question concerning compatibility of the XW-41 Warhead in the NAVAHO warhead compartment.

(b)(1), (b)(3)

(b)(1), (b)(3)

The missile could be redesigned to provide more clearance between bulkheads and warhead, and it was proposed that the NAVAHO be made a desired, rather than a mandatory, carrier of the XW-41.[18]

On May 9, 1957, the Air Force Special Weapons Center requested Sandia to design a system for automatic deployment of the TX-41 parachute. By referring this design to Sandia, it became possible to include the retardation system within the sealed portion of the bomb. This provided better control of the parachute storage environment and extended the parachute repack interval.[19] Sandia subsequently designed a drogue-gun which, when fired, initiated the parachute deployment sequence.

The Assistant Secretary of Defense notified the Atomic Energy Commission May 27, 1957, that the Air Force had canceled the compatibility requirements for the XW-41 Warhead in the B-58 Pod application.

(b)(3)

The joint working group for the NAVAHO had been activated, but rumors had circulated that the missile would be canceled.[21] The Air Force Special Weapons Center notified Sandia June 5, 1957 that informal information indicated the program would be continued on an expedited basis, but not on the high priority it had enjoyed up to this point. Warhead flight testing would be delayed until mid-1960, with an operational date a year later.

(b)(3)

The Air Force Special Weapons Center notified Sandia November 25, 1958 that the Strategic Air Command had decided to always release the TX-41 from the B-47 and B-52 aircraft in the retarded condition. Thus, there was no requirement for an option-selector switch, and the bomb could be designed so that the parachute would always deploy upon bomb release.[48]

Sandia wrote to Field Command December 8, 1958, discussing the need for additional safing devices on the TX-41 Bomb. Sandia pointed out that the Air Force Nuclear Weapon Safety Group had reported that the TX-41 was completely acceptable from the standpoints of accidental or premature detonation, provided that the bomb was not released in an armed condition. However, during airborne alert missions, the human element was predominant, and safety during these periods would be controlled by the probability of an arming signal being inadvertently furnished.

Sandia noted that any improvement in overall safety would have to reduce the foregoing possibility. All the systems studied had involved the installation of additional arming control switches in the aircraft at a crew station remote from the aircraft monitor and control station. Another possibility would be to install an additional switch at the aircraft monitor station, such that both switches were in series for weapon arming and in parallel for weapon safing. The first design would cause a slippage in time scales or require weapon retrofit, increase weapon complexity, and introduce logistics and compatibility problems, and Sandia recommended the second system.[49]

Field Command notified Sandia January 9, 1959 that the Air Force Special Weapons Center had again changed the requirements, and now desired selective free fall or retarded capability of the TX-41 Bomb. Reinstatement of the option-selector switch was requested.[50]

Meanwhile, Sandia had made a study of the TX-41 weapon features that would impede or deny access to bomb arming circuits, and proposed certain changes to Field Command.[51] These modifications were accepted February 9, 1959, and included deletion of the need for removal of the battery.[52] This change decreased weapon handling and increased the resistance of the bomb to actions of saboteurs and psychotics. It was noted that the firing set was inert and would only respond

to external signals furnished in a definite order. Additionally, between low-voltage battery and firing set, there were three separate safing devices that had to be armed in order for power to reach the firing set.[53]

The Mk 41 Bomb was released for pilot production in April 1959.[54] Subsequently, full design release was authorized in September 1959, with the publication of Report SC4813(TR), Description and Status at Design Release of the TX-41 Bomb.[55] This report noted that the bomb was 50 inches in diameter, 148 inches long, and weighed 10,500 pounds. (b)(1), (b)(3)

The report was presented to the October 21, 1959 meeting of the Special Weapons Development Board and accepted.[56]

The Division of Military Application had requested that a formal study be made of the compatibility of the bomb with B-70 aircraft.[57] The Radiation Laboratory, now renamed the Lawrence Radiation Laboratory, reported in a teletype of October 16, 1959 that the B-70 would subject the Mk 41 to a severe heat environment that would damage the nuclear components. There appeared to be two possibilities; to design a bomb capable of withstanding the temperature, or provide bomb cooling or insulation. The first approach would require a close study before it could be determined whether a new nuclear test would be required. The second approach appeared immediately feasible, but the modification would have to be made by the Air Force and the aircraft contractor.[58]

Meanwhile, much work had been done on the development of the aerodynamic shape of the Mk 41. Initially, three different shapes were tested in the wind tunnel; one similar to the Mk 21, another the same as the Mk 27, and a finless shape. A large nose flat on each model provided adequate space for mounting the contact-fuze crystals. The first wind-tunnel tests showed that a nose flat greater than 0.577 of the body diameter would produce dynamic instability.

The finless shape was found to be unstable. A decision was then made to use the Mk 21 shape, since it provided more room for fuzing-and-firing components, and stability was increased by adding a spoiler band. The Air Force reported that a

The fuzing and firing system used baro arming and fuzing in the air-burst option, and baro arming and impact-crystal operation in the ground-burst option. The impact crystals provided backup for the air-burst mode. Before takeoff, the baroswitch was set to the desired air-burst altitude and the safing switch turned to STRIKE. Inflight selection of either air burst or ground burst caused the fuzing-system control selector to unlock arming rods and open or close a 28-volt line to the fuzing elements.

When the bomb was released from the carrying aircraft the low-voltage thermal battery was connected to the weapon circuits, pullout generators activated low-voltage thermal batteries and started a timer, and two holes in the bomb afterbody were uncovered for pressure sensing. Timer contacts closed 9 seconds after release of the bomb, and deployed the parachute.

(b)(1), (b)(3)

Closure of arming contacts in the baroswitch provided an input to the rotary chopper. The output of this chopper charged the X-unit and armed a trigger circuit and external initiators. The bomb detonated on closure of fuzing elements in the baroswitch if air burst had been chosen. If ground burst had been selected, the bomb detonated when a firing signal was produced by the impact fuze.[64,65]

Field Command notified Sandia January 9, 1961 that Report SC4822(TR), Final Evaluation Report of the Mk 41 Bomb, had been reviewed in coordination with representatives of the interested Services. This review established that the design met all the requirements of the military characteristics, with some minor exceptions.

(b)(1), (b)(3)

The desired weight of 10,000 pounds had been exceeded by 500 pounds, but this was also acceptable in view of Department of Defense desires for the maximum possible yield. It had not been determined whether the bomb would be compatible with Weapon Systems 110A and 125A, since these aircraft were not yet available. Slight deviations in fuzing accuracy were acceptable, in view of the barometric system and the inherent errors of climatology. Thus, the design was declared acceptable to the Department of Defense.[66]

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January 1968

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AEC ATOMIC WEAPON DATA
Sigma

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HISTORY OF THE MK 42 WARHEAD(U)

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Weapon Systems

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Sandia Systematic Declassification Review
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there were no fractional-kiloton warheads being designed or considered for development with availability dates as early as 1961, which would be compatible with an unmodified HAWK missile. This was due to the small size of the warhead compartment, which was about 13 inches long.

(b)(1), (b)(3)

Since major modifications of the missile were required, it was felt that the implications of increased compartment length versus smaller warhead sizes should be studied further.[10]

The HAWK missile was designed for low-altitude defense and would be used in conjunction with the NIKE missile family. The HAWK weighed 1,250 pounds, and could operate from sea level up to 45,000 feet against single targets and to 30,000 feet against formation targets. It was capable of intercepting targets at ranges of 13 to 19 nautical miles with closing rates of 1,000 to 600 miles per hour.

Picatinny noted that the preliminary requirements included weapon kill as primary capability and carrier kill if weapon kill could not be achieved.

(b)(3)

Operation down to a 1000-foot altitude was desired, although 2500- to 5000-foot altitudes would be acceptable. Picatinny would proceed with a study of yield requirements and investigate the possibility of modifying the HAWK warhead compartment to accept nuclear warheads of the 10- to 12-inch-diameter class.[11]

On January 30, 1957, a member of Picatinny Arsenal met with representatives of Field Command, Radiation Laboratory, and Sandia.

(b)(1), (b)(3)

Timetable of Mk 43 Events

8/10/55	Assistant Secretary of Defense requests Atomic Energy Commission to cooperate with Navy in feasibility study of shock-resistant implosion bomb.
8/17/55	Assistant Secretary of Defense requests Atomic Energy Commission to cooperate with the Armed Forces Special Weapons Project in the TABLELEG study.
10/6/55	The above two projects are merged into one.
12/15/55	TABLELEG Committee studies three weapon designs; Step III to be the ultimate laydown design.

(b)(1), (b)(3)

8/1/56	TABLELEG report advocates design of Step III weapon.

(b)(1), (b)(3)

Spring 1957	Drop tests prove value of nose spike for weapon impact mitigation.
6/4/57	Approved military characteristics for TX-43 Bomb released.

(b)(1), (b)(3)

Early 1958	Separate noses for laydown and air-burst options to be provided.
4/23/58	Proposed ordnance characteristics of TX-43 presented to the Special Weapons Development Board and accepted, except for concern over safing provisions.

(b)(1), (b)(3)

(b)(1), (b)(3)

3/60	Mk 43 Mod 0 released for production.
9/28/61	Mk 43 Mod 1 released for production. Early deliveries of Mod 0.
9/62	Early deliveries of Mod 1 Nose.
6/19/62	Field Command notifies Sandia that final development report has been accepted.

History of the Mk 43 Bomb

In the early 1950's, the trend in military aviation was to fly higher and faster in order to defeat enemy defenses. Air-defense techniques, however, kept pace with increases in aircraft performance, and consequently a shift was made to attacks at low altitudes, where both radar and visual observation became less effective. This resulted in a demand for a weapon that could be released at low altitudes, be rugged enough to survive impact with the target, and then detonate by delayed-action fuze after pilot and aircraft were far enough away to survive the blast.

The Navy had expressed early interest in this type of weapon, and one result was the Mk 8 Bomb that could be used to penetrate water and even concrete submarine pens. However, the Mk 8 was a gun-type device, with an inherent handicap of nuclear inefficiency. The BETTY depth-bomb application of the implosion-type Mk 7 had been produced, as well as the even more rugged design of the Mk 34/LULU. However, both these weapons could withstand only water-entry shock, not impact with harder targets.

As smaller implosion and thermonuclear designs began to appear, and as improved weapon components were developed, the subject of shock-resistant weaponry continued to be periodically raised. The Assistant Secretary of Defense, August 10, 1955, requested the United States Atomic Energy Commission to cooperate with the Navy in a feasibility study of a lightweight, shock-resistant, implosion bomb which could be dropped at high speeds and low altitudes.

The above was followed by a similar letter dated August 17, 1955, requesting the Atomic Energy Commission to cooperate with the Armed Forces Special Weapons Project and the interested Services in a feasibility study of a new family of atomic weapons not more than 18 inches in diameter. One objective of this study was to determine if a weapon with free-fall characteristics and earlier time scales than the HOTPOINT study (which resulted in the Mk 34) could be developed. This was called the TABLELEG project.[1]

On August 31, 1955, the Joint Chiefs of Staff suggested that the foregoing projects be combined into an investigation of a single weapons family, emphasizing common employment characteristics and simplifying storage, handling, transportation, delivery-vehicle compatibility, and delivery tactics.[2] Subsequently, the Assistant Secretary of Defense forwarded this suggestion to the Atomic Energy Commission October 6, 1955, noting that the new weapons family was assigned top priority.[3]

(b)(1), (b)(3)

The initial approach would be to provide a bomb not more than 1500 pounds in weight, and which could survive release at high speeds and low altitudes. This bomb would have minimum tendency to ricochet, be nonpenetrating to any degree that would degrade surface-burst effects, and function reliably when dropped into shallow water against targets such as harbors and dams. The weapon shape would have low drag to permit efficient external carriage on aircraft.

A joint committee, with members from the Atomic Energy Commission and its contractors and representatives of the Department of Defense, was formed and held its first meeting November 17, 1955. This was the TABLELEG Committee, which examined the feasibility of developing a tactical/laydown family of weapons.

In the TABLELEG Committee meeting of December 15, 1955, the Navy proposed that three weapons be developed. A Step I weapon would provide the Navy with an urgently desired laydown weapon by 1958. This bomb would have the capability of being delivered at low altitudes (50 to 200 feet) and at speeds of Mach 0.6 to 1.4. It would have a single, simple time-delay fuze which would allow escape of the slowest carrying aircraft.

(b)(1), (b)(3)

This design was called HOTPOINT, and the bomb was subsequently stockpiled as the Mk 34.

A Step II weapon would be based on the TX-28 design and it, too, would provide the Services with a tactical family of weapons by 1958. This weapon would be

to 1000-g shocks being possible along any axis perpendicular to the longitudinal. The air-burst fuze would have to resist the opening shock of the parachute, estimated to be a maximum of 100 g's for releases at aircraft speeds of Mach 0.95.

The primary power supply would be thermal batteries, activated at time of release of the bomb. Parachute deployment delay timers would also be actuated at bomb release and, after a delay of 1/2 second for externally carried bombs and 1 second for internally carried bombs, would actuate the tail eject and parachute deployment mechanism.

An integrating deceleration switch would prevent weapon arming in the event of parachute failure on retarded deliveries, as it would have to experience a velocity change of 10 g-seconds. An impact switch would operate under a force of 30 g's and initiate a pyrotechnic timer. Operation of a trajectory arm switch for free-fall deliveries would be governed by the pressure differential between the fore and aft sides of a small block on the bomb case. The switch would be designed to close at a minimum velocity of 300 feet per second. A safe-separation timer would contain a spring-powered escapement timing element to close a set of electrical contacts at the end of two preset adjustable timing intervals and a fixed 9-second time. This component would contain two independent timing channels.

(b)(3)

It would have to be repackaged to meet the stringent space requirements of the TX-43, but its system would be similar to previous designs.

The rotary chopper would be a single-channel, motor-driven unit with an integral radio-interference filter. The device would convert battery voltage of 28 volts direct current into alternating voltage of the same magnitude and approximately rectangular waveform. The resultant power pulses would then be applied to a transformer-converter assembly, creating an output of 2400 volts direct current to charge the X-unit capacitor and provide a signal to the external initiators.

The X-unit would have one capacitor, with either a 4-probe gap or puncture switch connected to the central capacitor terminal. If a gap switch was used, four pulse

were expected with the latter application. Since wind-tunnel tests of the release and separation characteristics of internally carried streamlined shapes similar to the TX-43 had not been satisfactory in the past under high-speed conditions, it was essential that the separation problem be investigated as soon as possible.[13]

Field Command replied June 6, 1957, noting that B-47 compatibility could not be achieved without changing the existing design. However, if laydown option only would be acceptable, an internally carried version of the bomb could be provided by removing the air-burst fuze, thus reducing the length of the bomb 15 inches. The bomb could be made compatible with the F-105 by minor relocation of the bomb suspension rack.

Field Command noted that proposed drafts of the military characteristics for the TX-43 had virtually excluded the possibility of internal carriage of the bomb in the B-47, since a minimum length of 153 inches had been specified. It was felt that insistence on including the B-47 as a carrier might jeopardize the existing bomb design or result in a different design for internal carriage. Field Command noted that the design could not be provided with a turnaround design, similar to that of the TX-28, since the spike and parachute had to be at opposite ends of the weapon.[14]

The approved military characteristics for a tactical/laydown family of atomic weapons were meanwhile approved by the Military Liaison Committee June 4, 1957.[15]

(b)(1), (b)(3)

The bomb would be capable of delivery at high speeds and low altitudes with high accuracy and delivery safety. It would be capable of remaining in a completely assembled condition, ready for immediate use and without loss of functional reliability, for a period of at least 6 months.

The maximum diameter would be 18 inches. The length would be compatible with the designated carriers, but would not exceed 170 inches, and the maximum weight would be 1500 pounds.

(b)(1), (b)(3)

(b)(1), (b)(3)

The weapon would be capable of inflight selection of laydown burst, free-fall air burst, or retarded air burst. Four selectable burst heights would be provided, and the fireball was not to touch the ground. Releases at altitudes as low as 200 feet and speeds as high as Mach 0.95 were required, with releases down to 50 feet being desirable. For high-altitude releases, the bomb would be capable of delivery at 60,000 feet and a speed of Mach 2.1.[17]

Wind-tunnel tests had meanwhile been proceeding, and had proved that the fin span, as limited by carrier aircraft, would not provide proper ballistic stability. The span could have been increased by use of a folding-fin mechanism, but this was undesirable, from the standpoints of increased weight and decreased reliability.

(b)(1), (b)(3)

This made it possible to reduce the external diameter of the bomb to 16-1/2 inches, and this diameter, when coupled with the largest fixed fin span permissible, gave marginally acceptable aerodynamic performance.

(b)(1), (b)(3)

Los Alamos and Sandia commented on the tactical/laydown military characteristics in a letter to the Division of Military Application September 10, 1957. It was pointed out that a host of new and sometimes conflicting requirements had been added, and that the weapon design requested was infeasible.

The extensive list of weapon carriers included a wide range of aircraft types, and required the TX-43 to be capable of delivery at velocities ranging from

designs, Mod 0 and Mod 1, had been accepted by the Services as meeting the requirement for a single weapon including both laydown and air-burst capabilities.

It was recognized that the high shock requirements of a laydown design would not allow shipboard removal or insertion of the nuclear assembly. The 200-foot release altitude satisfied the military characteristics, but it was hoped that work would continue toward attainment of a 50-foot capability as soon as possible. 40

(b)(1), (b)(3)

The fuze switch pack was a potted unit containing printed-circuit boards, various explosive switches, diodes and cables. A 28-volt thermal battery was connected to a ready-safe switch operated electrically by the aircraft pilot. An inertial switch formed a safety device to prevent bomb arming in the event of accidental bomb release below minimum delivery speed, or in the event of parachute failure. A minimum force of 3 g's was required to activate this inertial switch, with a minimum of 8 g-seconds needed for complete operation.

A rotary chopper inverter transformed the battery output of 28 volts direct current into an alternating 28-volt rectangular waveform that was stepped up and rectified to provide high-voltage direct current for charging the capacitors of

the X-unit and the external initiators (neutron generators). The capacitor in the neutron generators was charged to a potential of 2200 to 2600 volts.

(b)(1), (b)(3)

Firing of this gap resulted in an arc discharge between two titanium tritide conductors in the source tube, thus producing tritium ions.

Firing of the spark gap allowed an energy storage capacitor to discharge the primary winding of a high-voltage pulse transformer.

(b)(3)

The weapon was provided with four fins, each having a frangible area at the outboard trailing edge. The unreefed ribbon parachute, developed by Wright Air Development Center, was 16 feet in diameter.[41]

Full-scale tests included drops onto a concrete target, at impact velocities of 46 to 117 feet per second, and at angles of 22 to 75 degrees to the horizontal target. Some test vehicles contained high explosives, and others held fuzing and firing components. Two tests were made at a temperature of -55°F. There were three fractures reported, all of which occurred when the weapon spike did not stick in the concrete. The high explosive did not detonate at impact, and the low-temperature units operated normally. Airdrops were started at the Salton Sea Test Base and continued at the Tonopah Test Range, where a 12-inch-thick concrete target became available in late 1960.[43,44]

Tests of the early designs of inertial latching switches showed that an excessively high minimum release speed was required and, for releases below an altitude of 300 feet, closure and lock-in were not accomplished with desired reliability.[45] The switch was redesigned for better operation and, due to a delay in the Mk 43 production schedule, it became possible to supply this new switch in time to meet first Mk 43 Mod 0 Bomb production in April 1961.[46,47,48]

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February 1968

RS 3434/25
AEC ATOMIC WEAPON DATA

Changes to Sigma 5 by authority of Nuclear Safety NAC 73/68 6/27/68. DOE/NV 3589 7/2/68 Mary P. Nichols

HISTORY OF THE MK 44 WARHEAD

SC-M-67-676

RS-3434 25
02/68

Information Research Division, 3434

Weapon Systems

Redacted Version

Sandia Systematic Declassification Review
RETAIN CLASSIFICATION
A. J. Duff 2/11/97
Reviewer Date

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THIS DOCUMENT CONSISTS OF 35 PAGES

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Classified By: Richard B. Craner
Classification Analyst, Org 4225
Date: 12/12/2007
Derived From: TCG-NAS-2, 03/97, DOE OC

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The Assistant Secretary of Defense requested the United States Atomic Energy Commission, November 1, 1954, to collaborate with the Navy Bureau of Ordnance in a study to determine the feasibility of developing a rocket-propelled atomic depth charge for attack of fast, deep-diving submarines. Recent improvements in submarine detection equipment had been made, and the Bureau of Ordnance wished to consider application of a nuclear weapon.[1]

The Division of Military Application forwarded the above request to the Santa Fe Operations Office, but pointed out that the scope of the study was quite broad and general, and that, until a particular weapon system had been selected, AEC participation should be confined to informal discussions. Time scales for the study had not been specified, and it was felt that a deliberate and unhurried examination should be conducted.[2]

Some months later, June 29, 1955, the Assistant Secretary of Defense requested a study of the feasibility of producing 10- to 12-inch implosion warheads.[3]

(b)(1), (b)(3)

Longitudinal accelerations of 100 g's for antiaircraft missiles and about 2000 g's for antisubmarine-warfare weapons were prescribed, and it was pointed out that the higher figure was appropriate for those weapons that would have to withstand water entry.

The attendees at the Board meeting felt that it would be possible to produce warheads of the desired size by 1959, in view of effort currently being expended on the XW-25 and XW-30 designs.

(b)(1), (b)(3)

(b)(1), (b)(3)

It was felt that the system could be made rugged enough for use as a depth charge.

Sandia reported that existing pulse transformers for external initiators were fairly bulky, and it was not apparent that their size and weight could be materially reduced. It was hoped that capacitors could be made smaller, and work was in progress on a toroidal design using a single winding, rather than the several individual capacitors used in existing components. However, costs would be high and reliability questionable for some time to come.

It was felt that completion of weapon development on schedule would depend largely on Sandia's work, and it was hoped that one design would be compatible with all carriers. Since NIKE and TERRIER were already available, the study would be based largely on these two missiles. One requirement, however, would be the high g-loading created by water entry, and it was suggested that shock-resistant designs be investigated.[4]

Field Command issued a study report November 1, 1955, which stated that an implosion weapon with an outside diameter of 11.75 inches and maximum length of 24 inches could be developed for use in several weapon delivery systems, including that of an ASROC (or antisubmarine rocket).

(b)(1), (b)(3)

The warhead would require no external power other than short pulses of 28 volts.[5]

(b)(1), (b)(3)

(b)(1), (b)(3)

The ASROC weapon system was described in a report issued by the Naval Ordnance Test Station January 28, 1957. The system had been designed to provide surface ships with a weapon for long-range attack of fast, deep-diving submarines. The system would be able to deliver either an atomic depth charge or an acoustic homing torpedo, and both payloads would use the same fire-control launcher, motor-thrust termination and airframe. The atomic ASROC would have a range from 3,500 yards (2 miles), which was the minimum safe range for launching-ship safety, to 10,000 yards (5-3/4 miles).

Warhead electrical arming would be initiated at water impact when, and only if, minimum safe range had been assured. A fixed time delay of 2 seconds after water impact would be provided to allow for complete warhead arming. Shallow-water hydrostats would assure that the depth charge had entered a water environment. The power source for the high-voltage system for warhead detonation could be removed or reinstalled with the weapon in place on the launcher.

The arming and fuzing functions would be divided into three main phases: Pre-launch, airflight, and underwater operation. Prior to launch, the arm/safe switch would be manually operated to the ARM position. When the rocket motor was ignited at launch, the weapon low-voltage power supply would be activated by the fire-control signal and the range determined by terminating the rocket thrust at the correct velocity to achieve proper range. This termination signal would be furnished by a range control device containing an integrating accelerometer and

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Timetable of Mk 47 Events

1/9/57 Assistant Secretary of Defense notifies the United States Atomic Energy Commission that the Navy is developing the POLARIS missile, and requests cooperation in a joint feasibility study of appropriate warheads.

5/27/57 Feasibility study issued, reporting that a suitable thermonuclear warhead could be provided through normal development of designs scheduled for test.

(b)(1), (b)(3)

11/22/57 Division of Military Application requests acceleration of the XW-47 program to meet an operational availability date of December 1959 with emergency-capability warheads.

(b)(1), (b)(3)

1/28/58 Military characteristics of the POLARIS warhead approved by the Military Liaison Committee.

(b)(1), (b)(3)

3/6/58 Sandia forwards development-program definition of the XW-47 Warhead to the Albuquerque Operations Office.

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10/6/61 Field Command notifies Sandia that Final Evaluation Report of the Mk 47 Warhead has been accepted by the Services.

(b)(1), (b)(3)

11/62 Mk 47Y2 Mod 2 released for production.

(b)(1), (b)(3)

2/27/63 Mk 47Y2 Mod 2 achieves production.

7/64 Mk 47 Warhead production completed.

(b)(3)

History of the Mk 47 Warhead

The Chief of Naval Operations wrote to the United States Atomic Energy Commission, September 14, 1956, noting that work was proceeding on a Fleet Ballistic Missile powered by solid propellant. Calculations had indicated that if a suitable warhead with a weight of 600 pounds could be produced, the missile could be considerably reduced in size. A smaller missile would offer both operational and logistic advantages to Fleet employment and would permit improvements in missile design. (b)(1), (b)(3)

The Assistant Secretary of Defense notified the Atomic Energy Commission January 9, 1957, that the Department of the Navy was developing the POLARIS, a sea-based, surface-to-surface ballistic missile for use against land targets. The Atomic Energy Commission was requested to cooperate with the Navy and the Armed Forces Special Weapons Project in a joint feasibility study of a warhead for this missile.

The POLARIS, a submarine-launched, two-stage solid-propellant rocket with inertial guidance, would have a diameter of 5 feet, length of 28 feet, gross takeoff weight of 33,000 pounds, and a range from 1,200 to 1,500 nautical miles. The warhead would be carried in the nose cone, and the nuclear device could weigh up to 600 pounds. (b)(1), (b)(3)

It was noted that the warhead parameters were relatively stringent, but that the Navy would accept an interim warhead with a smaller yield. It was felt that the warhead would have to be integrated with the nose cone to properly meet design objectives.[2]

Both the Los Alamos Scientific Laboratory and the University of California Radiation Laboratory were requested to participate in the study, but the major effort was provided by the Radiation Laboratory.[3] A feasibility study report was released May 27, 1957, which stated that no currently stockpiled warhead

was adaptable to POLARIS, but that straightforward development of devices planned for future tests should provide a suitable thermonuclear design. (b)(1), (b)(3)

The Navy was designated cognizant agent for the Department of Defense, with normal Armed Forces Special Weapons Project relationships.[5]

A POLARIS Re-entry Body Coordinating Committee was formed and held its first meeting July 29, 1957. It was noted that the re-entry body would include an aerodynamic cone, heat sink, warhead, adaption kit, and attitude controls. The total re-entry body weight, including warhead, would not exceed 835 pounds. (b)(1), (b)(3)

Timetable of Mk 48 Events

4/28/54	Army expresses interest in development of small low-yield projectile.
5/14/54	Secretary of Defense authorizes study of implosion-type projectile.
4/4/55	Work by the University of California Radiation Laboratory results in request by the Secretary of Defense for a feasibility study of an 8-inch implosion shell.

(b)(1), (b)(3)

9/20/56	Assistant Secretary of Defense requests United States Atomic Energy Commission to concentrate on atomic artillery shells of 155mm (6.1 inches) diameter.
7/12/57	Assistant Secretary of Defense requests that 155mm atomic implosion projectile be developed.
5/14/58	Developmental guidelines between Atomic Energy Commission and Department of Defense for development of 155mm shell issued.

(b)(1), (b)(3)

8/4/59	Military characteristics approved by the Military Liaison Committee.
11/6/59	Sandia forwards development program definition to AEC.

(b)(1), (b)(3)

3/23/60	Military Liaison Committee suspends higher yield requirement.
1/63	Mk 48 Mod 0 Shell design released.
10/26/63	Early production of Mk 48 Mod 0 Shells.
5/64	Final development report approved and published.

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RS 3434/29

History of the Mk 48 Shell

The predecessor of the Mk 48 Shell was the Mk 33, an 8-inch-diameter, artillery-fired atomic projectile. While this latter shell was still being designed, the Under Secretary of the Army wrote to the United States Atomic Energy Commission, April 28, 1954, expressing interest in the possibility of developing an even smaller diameter projectile with a very low yield, and a broad study was subsequently authorized by the Secretary of Defense May 14, 1954.

The intent of this study was to investigate the possibility of using implosion techniques in an atomic artillery shell, rather than the gun method used in previous shell designs, but the state of the art was not sufficiently well advanced. Much work was, however, accomplished in the ensuing 12 months by the University of California Radiation Laboratory and resulted in a request from the Secretary of Defense to the Atomic Energy Commission, April 4, 1955, for a feasibility study of an 8-inch shell having advanced nuclear techniques. (b)(1), (b)(3)

(b)(3)

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The Army informed Sandia November 24, 1961 that nomenclature of the 155mm projectile was changed from T358 to XM454 to prevent unclassified associations indicating the existence of the project for developing the atomic projectile.[27]

An amendment to the military characteristics, approved by the Military Liaison Committee June 26, 1962, deleted surface-burst preclusion. Contact detonation of shell with target was desired.[28] Another amendment was approved by the Military Liaison Committee September 19, 1962. This required that the shell be designed to allow it to be air-dropped in its container and survive impacts causing an 80-g deceleration.[29,30]

Meanwhile, components and complete projectiles had been subjected to laboratory functional and environmental tests simulating operational conditions, and to full-scale howitzer firings in instrumented projectiles. The items were first tested to determine their ability to operate properly as individual components. They were then assembled into subsystems, and finally into complete projectiles, and futher tested to determine their physical and electrical compatibility and their ability to function as a system. These tests were initially conducted under normal laboratory conditions; then under conditions of natural environmental extremes; then under the environments imposed by the application, such as ground handling, howitzer firing, etc.; and finally under the combinations of natural and artificial environments that would be encountered in actual use. All test results indicated that the system was more than adequate.

Production of the first unit, originally scheduled for June 1962, was delayed to October 1962, then to March 1963, and finally to October 1963, with corresponding changes being made to associated program dates. The Mk 48 Mod 0 Shell was given complete engineering release in January 1963, and production of the first projectiles was effected October 26, 1963.[31]

Report SC4871(WD), Final Development Report for the Mk 48 Mod 0 Warhead, was forwarded February 1964 to the Design Review and Acceptance Group, and was

subsequently approved and published in May 1964. (b)(1), (b)(3)

It was integrated with a number of components supplied by the Department of the Army to form the XM454, an artillery-fired atomic projectile designed to be fired from 155mm howitzers equipped with either M1A1 or T258 tubes. The maximum range of the projectile was 14,000 meters, or 8.5 miles. The minimum fuze-setting range was 1650 meters, or about 1 mile, which provided safe distance from nuclear detonation. The projectile was 155mm (6.1 inches) in diameter, 34 inches (5.57 calibers) long, and weighed 120 pounds.

(b)(1), (b)(3)

11. SRD Ltr, RS 8232/5150, Division of Military Application to San Francisco and Albuquerque Operations Offices, dtd 5/23/58, subject, Memorandum of Agreement between the AEC and DOD for the Development of a 155mm Implosion Type Atomic Artillery Shell. SC Central Technical Files, XW-48, 1-7, Livermore.

12. SRD Ltr, RS 3466/69944, Albuquerque Operations Office to Distribution, dtd 6/18/58, subject, Memorandum of Agreement between the AEC and DOD for the Development of a 155mm Implosion Type Atomic Artillery Shell. SC Central Technical Files, 48 Program, 1-3.

13. SRD Ltr, RS 8123/57, Division 8123 to Department 8120, Sandia Corporation, dtd 6/25/58, subject, Investigation Report on the TX-48 Components Proposed by Picatinny. SC Central Technical Files, 48 Program, 1958-1960.

14. (b)(3)

15.

16. CRD Ltr, Division of Military Application to Albuquerque Operations Office, dtd 4/16/59, subject, TX-48 Program. SC Central Technical Files, 1-1, Livermore.

17. (b)(3)

18. SRD Ltr, RS 3466/78825, Division of Military Application to Albuquerque Operations Office, dtd 8/18/59, subject, Military Characteristics for the XW-48. SC Central Technical Files, 48 Program, 1-6.

19. SRD Report, RS 8232-2/1008, Sandia Corporation, Livermore, to Distribution, dtd 5/64, subject, SC4871(WD), Final Development Report for the Mk 48 Mod 0 Warhead. SC Reports Files.

20. (b)(3)

21. SRD Ltr, RS 8000/80, Lawrence Radiation Laboratory and Sandia Corporation, Livermore, to Albuquerque Operations Office, dtd 12/3/59, subject, Military Characteristics of the XW-48 Warhead. SC Central Technical Files, 48 Program, 1-6.

22. (b)(3)

23. TSRD Report, RS LXI-5758, United States Atomic Energy Commission to Distribution, dtd 5/1/60, subject, Weapons Development Status Report. SC Files.

24. SRD Ltr, RS 8100/182, Lawrence Radiation Laboratory and Sandia Corporation, Livermore, to Albuquerque Operations Office, dtd 6/15/60, subject, Military Characteristics of the XW-48 Weapon. SC Central Technical Files, 48 Program, 1-6.

25. CRD Ltr, Lawrence Radiation Laboratory and Sandia Corporation, Livermore, to Picatinny Arsenal, dtd 3/2/60, subject, Reply to ORDBB-TWI-00455. SC Central Technical Files, TX-48, 2-, Livermore.

26. SRD Ltr, RS 8100/214, Sandia Corporation, Livermore, to Albuquerque Operations Office, dtd 1/15/61, subject, Military Characteristics of the XW-48 Warhead. SC Central Technical Files, 48 Program, 1-6.

27. CRD Ltr, Army Ordnance Department to Sandia Corporation, dtd 11/24/61, subject, Change in Nomenclature. SC Central Technical Files, XW-48, 1-8, Livermore.

28. SRD Ltr, RS 3446/53421, Division of Military Application to Albuquerque Operations Office, dtd 7/9/62, subject, Military Characteristics for XW-48. SC Central Technical Files, 48 Program, 1-6.

29. SRD Report, RS 3446/54895, Military Liaison Committee to Distribution, dtd 9/19/62, subject, Military Characteristics for the XW-48. SC Central Technical Files, 48 Program, 1-6.

30. SRD Ltr, RS 3446/54893, Division of Military Application to Albuquerque Operations Office, dtd 10/4/62, subject, Military Characteristics of the XW-48. SC Central Technical Files, 48 Program, 1-6.

31. SRD Report, RS 8000/244, Sandia Corporation to Distribution, dtd 10/25/63, subject, Major Assembly Release, Mk 48 Mod 0. SC Central Technical Files, XW-48, 2-5 to 2-14, Livermore.

32. (b)(3)

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RS 3434/29

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The intent of this study was to investigate the possibility of using implosion techniques in an atomic artillery shell, rather than the gun method used in previous shell designs, but the state of the art was not sufficiently well advanced. Much work was, however, accomplished in the ensuing 12 months by the University of California Radiation Laboratory and resulted in a request from the Secretary of Defense to the Atomic Energy Commission, April 4, 1955, for a feasibility study of an 8-inch shell having advanced nuclear techniques. (b)(1), (b)(3)

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Timetable of Mk 48 Events

4/28/54	Army expresses interest in development of small low-yield projectile.
5/14/54	Secretary of Defense authorizes study of implosion-type projectile.
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(b)(1), (b)(3)

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(b)(1), (b)(3)

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(b)(1), (b)(3)

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10/26/63	Early production of Mk 48 Mod 0 Shells.
5/64	Final development report approved and published.

Other components included a corona regulator tube, ceramic spark gap, and an inertial or setback switch. If the tube could not be designed to resist firing shock, other methods of regulation were available that could meet requirements of small size, rugged construction, and dependable operation. An extensive reliability study of the spark gap would have to be made. Due to experience gained on other designs, it was felt that the setback switch would impose no particular problems.[13]

The Army informed Sandia July 16, 1958 that, as the caliber of the implosion shell decreased, the magnitude of the associated engineering problems increased. It was therefore suggested that detailed consideration be limited to the design of a shell with a minimum diameter of 155mm. It was recommended that development engineering be authorized for a shell for the 155mm howitzer and the 175mm gun, but that general small-caliber research be continued.

(b)(1), (b)(3)

(b)(1), (b)(3)

(b)(3)

The higher yield, however, was desired and would be retained in the military characteristics.[23]

The Military Liaison Committee forwarded an amendment to the military characteristics May 2, 1960. This required that the XW-48 be compatible with M1A1 and T258 howitzers.[24] The Lawrence Radiation Laboratory and Sandia had previously informed Picatinny Arsenal that it was not possible, either through calculations or completed tests, to estimate with confidence the ability of the projectile to withstand the T258 environment, as Picatinny had indicated that this new application would subject the shell to angular accelerations 25 percent greater than previously anticipated. However, suitable tests would be conducted.[25]

These tests were subsequently made at the Army's Yuma, Arizona, test station. Linear accelerations of 12,000 g's were recorded, together with angular accelerations of 190,000 radians per second per second, the T258 howitzer environment. No premature firings were experienced, and no damage to shell components resulted. Thus, Sandia notified Albuquerque Operations Office January 15, 1961 that the T258 howitzer and XW-48 Shell were compatible.[26]

subsequently approved and published in May 1964. (b)(1), (b)(3)

It was integrated with a number of components supplied by the Department of the Army to form the XM454, an artillery-fired atomic projectile designed to be fired from 155mm howitzers equipped with either M1A1 or T258 tubes. The maximum range of the projectile was 14,000 meters, or 8.5 miles. The minimum fuze-setting range was 1650 meters, or about 1 mile, which provided safe distance from nuclear detonation. The projectile was 155mm (6.1 inches) in diameter, 34 inches (5.57 calibers) long, and weighed 120 pounds.

(b)(1), (b)(3)

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HISTORY OF THE MK 49 WARHEAD (U)

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Weapon Systems

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Information Research Division, 3434

Classified By: Richard B. Craner
Classification Analyst, Org 4225
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Sandia Systematic Declassification Review
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Mk 49 Mod 3

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1/60	Mk 49 Mod 3 Warhead design released.
3/11/60	Mk 49 Mod 3 Warhead authorized for application to THOR and JUPITER missiles. Early production accomplished by retrofit of Mk 49 Mod 1 Warheads.
6/60	New production of Mk 49 Mod 3 Warheads.
8/16/61	Final evaluation report of Mk 49 Mod 1/3 Warheads accepted by Military.

Mk 49 Mod 4

10/3/58	XW-49-X1 Warhead proposed for use with ablation nose cones.
10/21/59	Proposed ordnance characteristics of XW-49-X1 presented to Special Weapons Development Board.

(b)(1), (b)(3)

4/26/60	Mk 49 Mod 4 design released and early production achieved.
10/4/63	Final development report of Mk 49 Mod 4 accepted by Field Command.

Mk 49 Mod 5

4/24/62	Division of Military Application requests Sandia to provide JUPITER warhead with permissive device to prevent unauthorized detonation.
9/25/62	Mk 49 Mod 5 design released, incorporating coded switch pack.
9/29/62	Mk 49 Mod 3 Warheads retrofitted to Mod 5.
5/64	Final evaluation report of Mod 5 published.

Mk 49 Mod 6

12/63	Authorization released to incorporate self-destruct unit into some Mk 49 Mod 3 Warheads.

3/64	Initial delivery of Mk 49 Mod 6 Warheads.
7/18/65	Final evaluation report of Mod 6 accepted by Field Command.

History of the Mk 49 Warhead

In mid-1956, Los Alamos Scientific Laboratory and Sandia started to investigate warhead designs that could be used in connection with ATLAS and TITAN intercontinental ballistic missiles and JUPITER and THOR intermediate-range ballistic missiles. These studies culminated in development of the XW-35 and XW-35-X1 Warheads.

(b)(1), (b)(3)

The XW-35-X1 was a new configuration designed to produce a higher yield per pound, and was to follow the XW-35 in development by about one year.

Due to delays in missile availability, it became apparent that the XW-35-X1 would become operational at the same time as the earliest of the above missiles (with exception of JUPITER) and that the XW-35 design could be canceled.

(b)(1), (b)(3)

A decision was then made to cancel the XW-35, use the modified XW-28 for JUPITER, and apply the XW-35-X1 to all four missiles.

(b)(3)

Since THOR and JUPITER squadrons were scheduled for deployment in late 1958 and the XW-35-X1 Warhead would not be available in time, modified Mk 28Y1 Warheads would be supplied for the interim period.[1]

A meeting with General Electric, designers of the nose cone for the ATLAS, TITAN and THOR, was held December 9, 1957, and it was noted that the modified Mk 28Y1 Warhead would be renamed the XW-49.[2] This warhead would contain no internal power, as this would be supplied by the missile adaption kit. It was felt that the XW-49 could be produced in 1958.

(b)(1), (b)(3)

(b)(1), (b)(3) The warhead would be sealed and pressurized. The firing system would be checked after assembly and subsequently require only continuity and pressure monitoring in field or stockpile. There would be no component replacement permitted and no reason to break the warhead seal after initial assembly.[1]

The Mk 49 Mod 0 Warhead was design released in March 1958,[3] and early units entered stockpile in September 1958.[4] Sandia presented Report SC4161(TR), Description and Status Report at Design Release of the W49-0 Warhead, to the April 23, 1958 meeting of the Special Weapons Development Board.[5] The report noted that the Mk 49 Mod 0 was a thermonuclear warhead designed for early-emergency-capability use in JUPITER and THOR missiles. The warhead was 20 inches in diameter and 54.2 inches in length, exclusive of mounting provisions.

(b)(1), (b)(3) Field testing was limited to monitoring the internal warhead pressure every 30 days and checking electrical continuity just before mating the warhead to missile re-entry vehicle.

The report noted that the Mk 49 Mod 0 was the first warhead system to use a rotary chopper inverter/converter to change low-voltage direct current (28 volts) into high-voltage direct current (2200 volts). When proper signals were applied to both chopper and converter, the applied voltage was interrupted, transformed, rectified and used to charge the X-unit capacitor storage bank. To complete arming functions, a low-voltage direct current was applied to boosting-gas reservoir and valve assembly to release deuterium-tritium gas into the sealed pit.

The Mk 49 Mod 0 Warhead could be fired by either one of two signals. The air-burst option applied a 28-volt direct-current signal to a high-turns-ratio, low-impedance pulse transformer. The stepped-up voltage was applied to one probe of a dual-probe spark gap, ionizing the gap and releasing energy stored in the X-unit capacitor bank to the detonators, firing the warhead.

In the contact-burst option, a 250-volt direct-current signal was developed by contact crystals and applied to the grid of a cold-cathode thyratron trigger tube,

causing the tube to conduct. This discharged the capacitor in the plate circuit through the primary of the pulse transformer, and voltage generated in the secondary was applied to the second probe of the spark gap. This ionized the gap, the capacitor bank discharged into the detonators, and the warhead detonated.

(b)(1), (b)(3)

The firing system included X-unit, trigger circuit, rotary choppers, converter, arm/safe switch, and filter package. The boosting-gas reservoir and valve were mounted within the warhead pressure container. This container, composed of warhead case and pressure cover, housed warhead components and protected them from storage and operational environments. A pressure switch and humidity indicator were provided within the container to monitor internal pressure and humidity.

(b)(1), (b)(3)

Based on relative results of these two tests, and the fact that the nuclear testing

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moratorium was approaching, Los Alamos proposed, June 16, 1958, that the XW-35 program be canceled in favor of the XW-49. This suggestion was approved by the Division of Military Application, July 3, 1958.[7]

The United States Atomic Energy Commission wrote to the Deputy Secretary of Defense, July 8, 1958, reporting the decision to abandon the XW-35 program in favor of the XW-49.

(b)(1), (b)(3)

Sandia notified Albuquerque Operations Office, July 17, 1958, that the Mk 49Y1 Mod 0 Warhead would be delivered to stockpile in the near future. However, it did not appear appropriate to make the release until an acceptable number of successful warhead flights had been completed in various missiles. Schedules called for four THOR systems flights, and three system and two component flights in JUPITER by late 1958; and these would be the bare minimum to support an application release of warhead and missile. However, before the end of 1958, Sandia would issue an emergency-capability release to permit warhead-missile deployment pending availability of adequate flight-test information.[10]

An amended release of the Mk 49Y1 Mod 0 Warhead was made August 29, 1958. It was noted that satisfactory tests of this warhead had been performed in simulated environments typical of JUPITER and THOR, and application release for use in these missiles was authorized.[11]

By April 29, 1959, three warheads had been flight tested on THOR. Flight data indicated that the warhead experienced a relatively mild environment and that the warheads functioned as intended, in both air and contact burst. Six warheads had been tested on JUPITER. Of these, one test was successful, two were unsuccessful due to missile failure, two unsuccessful due to nose-cone failure, and one unsuccessful due to

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fuzing-system failure. Despite this poor showing, it was noted that these warheads had also experienced a relatively mild environment and that the weapons would have functioned properly if the correct fuzing signal had been given.[12]

The Mk 49Y2 Mod 0 Warhead was released July 2, 1959 for use with the ATLAS missile. One flight had been made, and this also indicated that the warhead could adequately resist the missile environment.[13] The Mk 49Y1 Mod 0 for the ATLAS was released July 29, 1959.[14]

Mk 49 Mod 1 Warhead

Development of a Mk 49 inertial switch was ~~prepared~~ proposed in May 1958. This device would prevent warhead arming until the weapon had experienced a re-entry deceleration environment, and prevent premature detonation caused by tester malfunctions, procedural mistakes, or acts of sabotage.[15]

An amendment to the military characteristics was approved by the Military Liaison Committee October 21, 1958. This requested that a sensing device be built into the Mk 49 Warhead, to be actuated as late in the missile acceleration phase as possible, so as to reduce the possibility of nuclear detonation through accident or sabotage.[16] The Department of Defense had requested that this device be located so that access was difficult and time-consuming, and to protect against fire or other accidents. It was suggested that all existing Mod 0 Warheads be retrofitted with the device, thus resulting in the Mod 1.

Initial release of Mk 49Y1 Mod 1 and Mk 49Y2 Mod 1 Warheads was made in June 1959, and early production was attained in October 1959 by retrofit of Mod 0 Warheads. The Mk 49 Mod 1 was identical in all respects to the Mk 49 Mod 0, with exception of the inertial switch. This switch closed and latched after experiencing a force of 3 to 10 g's, with a total input of 10 g-seconds.

Three 28-volt direct-current inputs were required for arming. These could be received simultaneously, but, if in sequence, the order had to be as follows: (1) Continuous input to the chopper motor, (2) continuous input to the voltage converter,

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and (3) pulsed or continuous input to the boosting-gas valve.

(b)(3)

Two alternate methods of firing the trigger circuit were provided. The first was 28-volt direct current, and was used only in the air-burst option. The other was a 250-volt direct-current pulse, and could be used for either ground or air-burst.

Fuzing signals varied with the missile. JUPITER issued signals singly, in the above order, for arming, by cam-actuated switches on a safing and arming sequencer. Either a radar-air-burst or a contact-crystal signal was then received. The ATLAS and THOR fuzing system provided arming signals simultaneously and detonated the warhead by means of a baroswitch for air-burst option or piezoelectric crystals in the contact option.[17]

Mk 49 Mod 2 Warhead

The Mk 49 Mod 2 Warhead would have been incorporated in the Mk 3 re-entry vehicle in the ATLAS missile. The design would have been internally initiated, as in Mods 0 and 1. A decision to change to external initiators (see the Mk 49 Mod 3 Warhead) resulted in canceling the Mod 2, prior to production, in favor of the Mk 49 Mod 4.

Mk 49 Mod 3 Warhead

A product change proposal dated November 5, 1959 was designed to conserve reactor products.

(b)(1), (b)(3)

The Mk 49 Mod 3 Warhead was design released in January 1960, and authorization for use of this warhead with JUPITER and THOR missiles was issued March 11, 1960.[19] Early production by retrofit of Mk 49 Mod 1's was accomplished during March 1960, and new production started in June 1960.

(b)(1), (b)(3)

The electrical system consisted of the Mk 28 capacitor bank

Mod 0 Warhead, but a new warhead case and pressure cover would be provided. The case would have provisions for mounting nose cap and flare skirt, and the pressure cover would have to withstand the loading created by attachment to the missile. The portion of the warhead case exposed in the re-entry vehicle would be covered with ablation material.[22]

Sandia presented the development program definition of the XW-49-X1 to Albuquerque Operations Office March 16, 1959. Warhead development was directed toward design release in May 1959 and early production in February 1960. The new warhead case would contain modified Mk 49 Mod 0 plastic, same nuclear system, and Mk 49 Mod 1 firing set.[16]

Sandia presented Report SC4293(TR), Proposed Ordnance Characteristics of the XW-49-X1 Warhead, to the October 21, 1959 meeting of the Special Weapons Development Board.[24] The report noted that the warhead was being designed for incorporation in the Mk 3 re-entry vehicle. Carry-over components from the Mk 49 Mod 0 and Mod 1 Warheads would be used wherever possible. Significant changes included major redesign of warhead case section, new interface provisions, and improved sealing features.

(b)(3)

The report was accepted and forwarded to the Division of Military Application.[25]

(b)(1), (b)(3)

Design release was scheduled for January 1960 and early production for April 1960.

(b)(3)

This change would lengthen the warhead by 2.1 inches. The major diameter would be 20 inches plus ablating material, maximum length 57.9 inches plus electrical connectors, and the weight about 1640 pounds without ablation material and 1732 pounds with ablation material.

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(b)(3)

Mk 49 Mod 5

On April 24, 1962, the Division of Military Application requested that the JUPITER warhead be provided with a permissive device to prevent unauthorized detonation.[32] Sandia stated that an expedited program could produce retrofit kits by late September 1962. To be compatible with the limited space available in the warhead firing section, separate environmental sensing devices and code switches would be installed.

A joint working group was established and met initially May 11, 1962. It was noted that this change would produce the Mk 49 Mod 5 and would increase the warhead weight by 12 pounds. The design was released September 25, 1962 and, within 4 days, two warheads had been retrofitted.[33,34] The Mod 5's were produced by retrofit of Mod 3's and involved replacing an inertial switch pack with a coded switch pack and substituting a new 2-piece pressure cover.[35]

Report SC4780(WD), Final Evaluation Report for the Mk 49 Mod 5 Warhead, was published in May 1964. This noted that permission had been given to deviate from normal development and production procedures in order to meet the retrofit date. Conversion hardware was produced from development rather than production drawings, the design group was given responsibility for acceptance of components, and all hardware, where possible, was 100-percent tested to establish its functional, electrical, structural and interchangeability characteristics.

The system operation of the Mk 49 Mod 5 was the same as the Mod 3, except that the environmental-sensing-device switches were not cross channeled, and therefore any switch failure would cause failure on one channel. Prior to launch, the coded switches were remotely armed to provide continuity through that part of the system.[36]

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HISTORY OF THE MK 50 WARHEAD (U)

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Timetable of Mk 50 Events

Early 1955 — Army Ordnance Corps requests Bell Telephone Laboratories to evaluate 1960-1970 air-defense problems. NIKE ZEUS antimissile missile proposed.

4/9/57 — Assistant Secretary of Defense requests United States Atomic Energy Commission to study feasibility of nuclear warhead for NIKE ZEUS.

(b)(1), (b)(3)

1/21/58 — Discussion of warhead for PERSHING, a surface-to-surface ballistic missile. Both Los Alamos Scientific Laboratory and University of California Radiation Laboratory propose warhead designs for PERSHING.

2/6/58 — Feasibility study of PERSHING warhead issued. Two warhead yields and weights proposed.

2/10/58 — Division of Military Application suggests that responsibility for development of NIKE ZEUS warhead be assigned to Los Alamos, due to number of programs assigned to the Radiation Laboratory.

3/3/58 — Assistant Secretary of Defense requests Atomic Energy Commission to develop warhead for NIKE ZEUS.

4/4/58 — Assistant Secretary of Defense requests Atomic Energy Commission to develop warhead for MINUTEMAN, an intercontinental ballistic missile.

5/6/58 — Albuquerque Operations Office reports completion of MINUTEMAN warhead study to Division of Military Application.

(b)(1), (b)(3)

Application of same warhead to NIKE ZEUS suggested.

5/21/58 — Assistant Secretary of Defense requests Atomic Energy Commission to conduct further feasibility study of warheads for PERSHING in two weight classes, 300 and 600 pounds.

(b)(1), (b)(3)

6/4/58 — Military Liaison Committee accepts proposal of Divison of Military Application that one warhead be developed for NIKE ZEUS, MINUTEMAN, PERSHING and HOPI missiles, with weight of 350 pounds.

On March 28, 1958, another missile program was proposed when the Military Liaison Committee requested the Atomic Energy Commission to develop a suitable warhead for MINUTEMAN. This was a three-stage, solid-propellant, intercontinental ballistic missile, the upper two stages of which could be used as an intermediate-range missile and the top stage as a short-range missile. The missile could carry either a 300- or 550-pound warhead, and it was anticipated that the missile system would be operational in mid-1962, with warheads being required in large numbers.[13] This program was subsequently authorized by the Assistant Secretary of Defense.[14]

Albuquerque Operations Office sent a teletype to the Division of Military Application May 6, 1958, reporting completion of the MINUTEMAN warhead study.

(b)(1), (b)(3)

The Assistant Secretary of Defense, May 21, 1958, requested the Atomic Energy Commission to cooperate in another feasibility study of warheads for the PERSHING missile system. Two warhead weight classes would be considered; 300 and 600 pounds. For the 300-pound design, the diameter would be less than 15 inches and the length about 40 inches. The 600-pound weapon would be about 18 inches in diameter and the length less than 50 inches.

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Availability date for both warheads would be compatible with missile development in late 1962, and both designs would be required in relatively large numbers.[16]

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(b)(1), (b)(3)

The Division of Military Application had suggested that a single warhead be developed for the NIKE ZEUS, MINUTEMAN, PERSHING and HOPI missile systems, and this proposal was accepted by the Military Liaison Committee June 4, 1958. The Services felt that the diameter of this universal warhead should be from 12 to 14 inches, length 38 to 44 inches, and weight about 350 pounds.[17]

The Division of Military Application forwarded the request for a feasibility study of two warheads for the PERSHING missile to Albuquerque Operations Office June 24, 1958. It was noted that activities in Operation Hardtack were directly related to this study, and that any report should be deferred until test results had been analyzed.[18]

Military characteristics for the NIKE ZEUS missile warhead were released by the Military Liaison Committee July 15, 1958. These noted that the warhead should be rugged, reliable and simple in design; easy and safe to test, monitor, inspect, store, transport and handle; be designed to minimize possibility of human error; and require a minimum of operational tests and maintenance.

(b)(1), (b)(3)

The warhead would be capable of remaining in alert condition on the launcher, ready to fire within 15 seconds, for a period of at least 4 years.[19]

These characteristics were forwarded by the Division of Military Application to Albuquerque Operations Office, August 6, 1958. It was requested that advice concerning warhead parameters be issued as soon as possible, together with information as to whether a single warhead could be designed for all four missiles.[20]

desired weights and yields could be developed on time scales compatible with the missile. The 650-pound warhead would be provided by minor rework of the XW-47 Warhead, and the 350-pound warhead would be furnished by the XW-50.[26]

(b)(1), (b)(3)

It was felt that the NIKE ZEUS could accept a warhead weighing up to 400 pounds, and it was requested that the Military be queried whether the XW-50 weight could be increased to this figure.

(b)(1), (b)(3)

Subsequently, the Air Force noted that MINUTEMAN could carry a 600-pound warhead, and it was decided to apply the XW-56 Warhead to this missile.[28] The HOPI missile was eventually dropped from consideration.

(b)(1), (b)(3)

The Director of Defense Research and Engineering notified the Military Liaison Committee June 19, 1959 that a review had been made of possible nuclear devices to be used in the XW-50 Warhead.

(b)(1), (b)(3)

The foregoing was followed by a letter from the Director of Defense Research and Engineering to the Atomic Energy Commission June 24, 1959, noting that the Joint Chiefs of Staff had determined that an operational requirement existed for

(b)(1), (b)(3)

The warhead was 14 inches in diameter, 15-3/8 inches at the mounting flange, 44 inches long and weighed about 412 pounds. Production of the XW-50-X1 was authorized in June 1961.[43]

(b)(1), (b)(3)

The Division of Military Application had requested that a prescribed action link be provided for the Mk 50/PERSHING.[45] After considerable study, Sandia notified Albuquerque Operations Office July 30, 1962 that incorporation of such device would make the warhead electrically incompatible with NIKE ZEUS. Modification was required, since the limited internal volume of the warhead required removal of self-destruct transverters to provide enough room for the prescribed action link. The device would be included in warhead production by late 1962, and the modified design would be called the Mk 50 Mod 1. Mk 50 Mod 0 designs for the NIKE ZEUS, released in December 1961, would be maintained in active status, but no production was authorized.[46]

Sandia subsequently notified Albuquerque Operations Office that diversion of firing sets for approaching test series would delay production of Mk 50 Mod 1's to March 1963. It was felt that this would allow the Army sufficient time to meet the overseas deployment date of March 1964 for PERSHING.[47]

Field Command notified Sandia September 14, 1962 that Report SC4555(WD), Interim Development Report for the Mk 50, had been reviewed in coordination with representatives of the interested Services. The review established that the design met all requirements of the approved military characteristics, except for the following: The warhead was slightly overweight, and this was acceptable. The ability of the warhead to withstand storage for 4 years was still under study. It was requested that a letter addendum be prepared to cover the Mk 50 Mod 1 design; otherwise, the report was acceptable to the Department of Defense.[48]

On October 19, 1962, Albuquerque Operations Office approved nomenclature for the Mk 50 Mod 1.[49]

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The firing set in the Mk 50 Mod 1 would not have a self-destruct system, but would incorporate a prescribed action link for PERSHING application only.[50]

An amendment to the military characteristics was released December 11, 1962. This required that a coded arming control device or prescribed action link be incorporated in the warhead for PERSHING application to provide an additional measure of command control.

(b)(3)

The device would be capable of being enabled while the missile was in the ready-to-launch condition. Errors in encoding, decoding, recoding, enabling and disenabling would not cause personal injury or weapon destruction.[51]

Early production of the Mk 50 Mod 1 Warhead was accomplished in March 1963. No production of Mk 50 Mod 0 for application to the NIKE ZEUS missile was authorized.

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HISTORY OF THE XW-51 WARHEAD (U)

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Weapon Systems

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Timetable of XW-51 Events

2/7/58 Assistant Secretary of Defense requests United States Atomic Energy Commission to assist in feasibility study of warhead for the FALCON, an Air Force air-to-air missile.

2/18/58 Phase 2 feasibility study reports that FALCON warhead could not be developed by February 1960. (b)(1), (b)(3)

2/19/58 Assistant Secretary of Defense requests Atomic Energy Commission to study feasibility of warhead for an Army ground-to-ground missile. Consideration to be given to a design that could also be used with the FALCON.

3/19/58 Special Weapons Development Board discusses NUTCRACKER weapons.

(b)(1), (b)(3)

(b)(1), (b)(3)

4/23/58 Special Weapons Development Board studies DAVY CROCKETT, an Army ground-to-ground missile.

(b)(1), (b)(3)

Sandia starts component development.

6/23/58 Assistant Secretary of Defense requests Atomic Energy Commission to develop one warhead for both FALCON and DAVY CROCKETT applications. An improved nuclear design, using less plutonium, to be provided as soon as possible.

7/16/58 Division of Military Application suggests that the Radiation Laboratory be assigned nuclear development responsibility for FALCON and DAVY CROCKETT warheads.

(b)(1), (b)(3)

9/24/58 Nomenclature of XW-51 assigned to FALCON and DAVY CROCKETT warhead development.

(b)(1), (b)(3)

It was expected that a fairly large quantity of these weapons would be required, with early deliveries starting in February 1960.[3,4]

The feasibility report was released by the Air Force Special Weapons Center February 18, 1958, and concluded that existing weapon commitments would not permit development of a warhead compatible with FALCON and which could meet the desired operational availability date.

(b)(1), (b)(3)

The Assistant Secretary of Defense notified the Atomic Energy Commission February 19, 1958 that the Army desired a lightweight, simple, ground-to-ground nuclear-weapon delivery system which could carry a small, low-yield warhead. This system would be used by the Battle Groups of the Pentomic Divisions. Study had indicated that an acceptable system might be developed in a relatively short period of time, and consideration of a suitable warhead was requested.

(b)(1), (b)(3)

It was hoped that the design could be produced by 1960, and it was requested that consideration be given to a warhead that could also be applied to the FALCON missile.[2]

The Special Weapons Development Board met March 19, 1958, and discussed a proposed series of low-yield, nuclear, ground-to-ground, close-support devices called NUTCRACKER which would supplement existing weapon systems. These devices would provide mobility, ability to fire on short notice, would limit effects to the Commander's area of responsibility, assure safety to friendly troops, and result in minimum damage to nontarget areas.

Since recoilless rifles had light weight and inherent accuracy, it was felt that these weapons might be used to deliver a nuclear payload. Sandia had previously

requested Frankford Arsenal to investigate the environment that a weapon launched from a recoilless rifle would experience, and results of the study had indicated that the rifle would subject the warhead to lower setback forces than were created by existing atomic artillery shells.

As a result of the study, two rifle systems had been proposed. One would have a diameter of 6 inches and be spigot-fired, with the diameter of the projectile being larger than the rifle bore. The other would have a diameter of 13 inches. The rifle barrels would be made of fiberglass and be discarded after each round.

(b)(1), (b)(3)

University of California Radiation Laboratory personnel described a warhead that could be used in the NUTCRACKER series.

(b)(1), (b)(3)

The Special Weapons Development Board met April 23, 1958, and noted that the DAVY CROCKETT, a member of the NUTCRACKER series suggested by Sandia, would be spigot-fired from a 6-inch recoilless rifle.[8] The system would have a useful range of 350 to 2000 meters, an overall weight of about 100 pounds, and could be transported by two men.

(b)(1), (b)(3)

A cruciform-shaped afterbody would be 33 inches long, and the range could be extended by providing a longer afterbody.[9]

(b)(1), (b)(3)

(b)(1), (b)(3)

Sandia started component development work. A safety switch would be needed for the DAVY CROCKETT application that would sense acceleration, but would not operate unless a minimum level of 1000 g's was experienced. A squib-initiated 28-volt thermal battery would be required with a rise time of less than 1 second and an output of 4 amperes. A timer would be squib-initiated and leave a 5-second interval.[11]

The Assistant Secretary of Defense notified the United States Atomic Energy Commission June 23, 1958, that it was technically feasible to develop suitable warheads for the FALCON or GAR-11 and the DAVY CROCKETT or the Battle Group Atomic Delivery System, and the Joint Chiefs of Staff had established a requirement for a single warhead for both applications.

(b)(1), (b)(3)

Sandia-Livermore sent a teletype to Albuquerque Operations Office, June 24, 1958, noting that the FALCON and DAVY CROCKETT missiles had different acceleration regimes. The FALCON experienced a boost phase of about 20 g's for 2 seconds, producing a speed of about 1700 feet per second above the velocity of the launch aircraft. The DAVY CROCKETT experienced an acceleration of 2500 g's, resulting in a speed of 500 feet per second. It appeared doubtful whether the same type of safety switch (to prevent premature detonation) could be designed and used.[13]

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The Division of Military Application requested Albuquerque Operations Office, July 16, 1958, to assign nuclear development responsibilities for the FALCON and DAVY CROCKETT warheads to the Radiation Laboratory. It was hoped that one warhead could be provided for both applications.[14]

The Army notified Sandia July 23, 1958, that recent developments in the Middle East had emphasized DAVY CROCKETT desirability, and that the Army had internally accorded this program the highest possible priority. The Secretary of the Army had recommended to the Department of Defense that this system be given a national urgency equal to that of the intercontinental ballistic missile and the antimissile missile.[15]

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Sandia notified Albuquerque Operations Office September 24, 1958, that nomenclature of XW-51 had been assigned to the warhead.[17] The military characteristics for an

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atomic warhead for the FALCON and DAVY CROCKETT were approved by the Military Liaison Committee October 21, 1958.

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If technically feasible, a warhead for both applications would be provided in one basic design.

Maximum economy of nuclear material was a major design objective. Other features of interest included safety from nuclear disaster to friendly troops and installations, acceptable reliability, minimum weight, simplicity and ease of maintenance, and minimum use of reactor products.[18]

The Division of Military Application, November 14, 1958, requested that the Lawrence Radiation Laboratory and Sandia join with the Air Force and the Army in development engineering of the FALCON and DAVY CROCKETT warhead installations.[19]

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The Group would reconvene December 4, 1958.[20]

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The design would also meet requirements for the DAVY CROCKETT system and would be capable of withstanding the acceleration imparted to the warhead by the recoilless rifle.

Glossary of XW-51 Terms

Air Force Special Weapons Center -- That element of the Air Force Systems Command having to do with compatibility testing of nuclear devices with aircraft. Located at Kirtland Air Force Base, Albuquerque, New Mexico.

Albuquerque Operations Office -- The local office of the Atomic Energy Commission (AEC) concerned with the operations of Sandia Corporation.

Armed Forces Special Weapons Project -- An interdepartmental agency formed to handle military functions related to atomic weapons.

Assistant Secretary of Defense -- Created by Department of Defense directive, June 30, 1953, as part of DOD reorganization. Handles research and development activities of the DOD.

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Department of Defense -- The Armed Forces, i.e., the Army, Navy and Air Force.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

Field Command -- The local office of the Armed Forces Special Weapons Project (Defense Atomic Support Agency), located on Sandia Base, Albuquerque, New Mexico.

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Hardtack -- A nuclear series of 72 tests. Hardtack I was held at the Pacific Proving Grounds from April 28 to August 18, 1958. The decision to declare a moratorium on testing resulted in Hardtack II, held at the Nevada Test Site between September 12 and October 30, 1958.

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Joint Chiefs of Staff -- A group composed of the Chiefs of Staff of the Army, Navy and Air Force, to determine policy and develop joint strategic objectives of the Armed Forces.

Kilogram -- A metric weight approximating 2.2 pounds.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Lawrence Radiation Laboratory -- A change of name for the University of California Radiation Laboratory (which see), effective October 1958.

Lenses -- As applied to nuclear weapons, lenses are elements of the high-explosive sphere, which are designed to produce an implosion. The lens charge is composed of high explosives of different burning rates and is so constructed and shaped as to change the explosion initiated by the detonators into an implosive force which converges smoothly on the nuclear materials.

Los Alamos Scientific Laboratory -- A nuclear design organization located at Los Alamos, New Mexico.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Military Liaison Committee -- A Department of Defense committee established by the Atomic Energy Act to advise and consult with the AEC on all matters relating to military applications of atomic energy.

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One-Point-Safe Weapon -- A weapon that will not produce a nuclear yield when detonated at one point on the surface of the high explosive.

Operation Hardtack -- See Hardtack.

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Radar -- Named for Radio Detecting and Ranging. Radars emit a pulse of high-frequency energy and measure the time lapse from that transmission to receipt of a reflected electrical "echo" from an object. This time measurement determines the distance of the object from the transmitting antenna of the radar.

Special Weapons Development Board -- Change of name for the Sandia Weapons Development Board, effective May 14, 1952.

Squib -- A device containing a small powder charge. When detonated, the resulting gas pressure closes a switch or performs a similar action. A light, quick-acting, one-shot device.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Ton (Yield) -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-ton yield is equivalent to the detonation effect of 2000 pounds of high explosive.

Tritium -- The hydrogen isotope of mass number 3.

University of California Radiation Laboratory -- A laboratory established at Livermore, California. Initially founded for work on thermonuclear designs.

Uranium-235 -- A radioactive element, an isotope of uranium-238.

Uranium-238 -- A radioactive element, atomic number 92. Natural uranium contains about 99.3-percent uranium-238; the rest is uranium-235.

Warhead -- A weapon carried to the target by missile.

13. SRD TWX, RS 8000/22, Sandia-Livermore to Albuquerque Operations Office, dtd 6/24/58. SC Central Technical Files, 54 Program, DAVY CROCKETT, 1958-9.

14. SRD Ltr, RS 3466/70375, Division of Military Application to Albuquerque Operations Office, dtd 7/16/58, subject, Warhead for DAVY CROCKETT and FALCON. SC Central Technical Files, 54 Program, DAVY CROCKETT, 1958-9.

15. SRD Ltr, RS 3466/70423, Chief of Research and Development, Department of the Army, to Sandia Corporation, dtd 7/23/58. SC Central Technical Files, 54 Program, DAVY CROCKETT, 1958-9.

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17. SRD Ltr, RS 1000/3293, Sandia Corporation to Albuquerque Operations Office, dtd 9/24/58, subject, Weapon Development Program Number Assignment. SC Central Technical Files, 51 Program.

18. SRD Report, Military Liaison Committee to Distribution, dtd 10/21/58, subject, Military Characteristics for Atomic Warhead for Battle Group Atomic Delivery (DAVY CROCKETT) System and the FALCON (GAR-11) Missile. SC Central Technical Files, Mk 54, 2-, 1959-60.

19. SRD Ltr, RS 3466/73449, Albuquerque Operations Office to Lawrence Radiation Laboratory and Sandia Corporation, dtd 11/25/58, subject, Phase 3 Authorization for a Warhead for DAVY CROCKETT and FALCON. SC Central Technical Files, 54 Program, DAVY CROCKETT, 1958-9.

20. SRD TWX, RS 3466/73486, Field Command to Picatinny Arsenal, dtd 12/1/58. SC Central Technical Files, 54 Program, DAVY CROCKETT, 1958-9.

21. SRD Report, RS 3466/73804, Los Alamos Scientific Laboratory to Distribution, dtd 12/8/58, subject, DAVY CROCKETT and GAR-11. SC Central Technical Files, 51/DAVY CROCKETT, NUTCRACKER.

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23. SRD TWX, RS 3466/73989, Division of Military Application to Albuquerque Operations Office, dtd 1/15/59. SC Central Technical Files, 54 Program, DAVY CROCKETT, 1958-9.

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HISTORY OF THE MK 52 WARHEAD (U)

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Information Research Division, 3434

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History of the Mk 52 Warhead

The Mk 52 resulted from the effort to provide the Army SERGEANT rocket with an appropriate nuclear warhead. An early meeting was held September 25, 1953, with representatives of the missile contractor (the Jet Propulsion Laboratory of the California Institute of Technology), the Armed Forces Special Weapons Project and Sandia in attendance. It was noted that the SERGEANT would be 30 inches in diameter, 35 feet long, weigh 10,000 pounds, and be able to carry a 1500-pound warhead to a range of 75 to 100 miles. The SERGEANT was a surface-to-surface, solid-propellant guided rocket, intended as a replacement for the CORPORAL, which carried a Mk 7 Warhead.[1]

The Division of Military Application, in a letter dated November 27, 1953, noted that the SERGEANT had not yet been approved as an atomic weapon carrier, and that Sandia participation should be limited to liaison and interchange of information to assist the Jet Propulsion Laboratory in preparing a system proposal.[2]

Little immediate warhead work was performed, but by late May 1955 Sandia studies indicated that it would be possible to provide a warhead to meet missile requirements of reliability, simplicity, ease of operation, freedom from countermeasures, ruggedness and safety. A thermonuclear design was suggested, since the higher yield and efficiency of such weapon would have size and weight advantages that would aid in achieving missile objectives.[3]

The Assistant Secretary of Defense notified the United States Atomic Energy Commission August 29, 1955 that early production of the SERGEANT missile was scheduled for May 1959. Request was made for participation in a joint feasibility study of suitable warheads for the system, in cooperation with the Army and the Armed Forces Special Weapons Project, and this request was subsequently forwarded to both Santa Fe and San Francisco Operations Offices.[4]

By mid-April 1956, two successful SERGEANT flight tests had taken place. The rocket was inertially guided, and continuous guidance correction during the missile flight

was provided. The range was controlled by extending the drag brakes of the missile for a specified length of time.

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The Army's Picatinny Arsenal had been studying possible fuzing systems and proposed that a radiating-type fuze be used, with options of air burst with contact backup, ground burst, and air burst with contact preclusion. It was felt that either inertial or barometric fuzing would not be sufficiently precise, as it was hoped to develop a burst-height accuracy of ±50 feet.

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A feasibility study group had meanwhile been formed, with representatives from Field Command, Picatinny Arsenal and Sandia. This group reported, July 25, 1956, that it would be about a year and a half before firm atomic-warhead information would be required for the SERGEANT program, and that consideration of warhead designs was premature. It was proposed that warhead selection, as well as completion of the feasibility study, be deferred until after the 1957 nuclear test series.[6]

Picatinny Arsenal requested information on the one-point-detonation characteristics of the nuclear design, so that an adequate safing system could be devised.

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Rocket design continued, with little work being done on the warhead. The feasibility study group again met December 3-4, 1957, and learned that the rocket operational availability date of mid-1962 might be shortened by almost a year.

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Picatinny Arsenal released the feasibility study report December 31. 1957.

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Typical targets were fighter airfields, command posts, headquarters, communication centers, supply and logistic installations, troop units, tanks and artillery.

The rocket was 31 inches in diameter, 31 feet long, and weighed 10,000 pounds at launch. It was composed of four major sections; propulsion, fins, guidance and warhead. The solid-propellant motor had a burning time of 28 seconds and reached a peak longitudinal acceleration of about 10 g's at burnout. The range was controlled by four simultaneously activated drag brakes which extended and retracted three times during the upward leg of the missile trajectory. The time that the brakes remained extended was determined by an internal computer which continuously compared the actual position and velocity of the rocket, as determined by an inertial platform, with the reference trajectory that the missile should be following for that particular range.

Time of flight varied between 120 and 200 seconds. About 22 seconds prior to impact, an arming decision was made, based on establishment of the square or window in space through which the missile would have to pass in order to receive an affirmative arming command. During the final 20 seconds of flight any necessary corrective maneuvers were performed.

The nose section for the warhead would have an overall length of 139 inches, with the base of the section having a diameter of 31 inches and tapering to a point. The warhead installation would be limited to a weight of 1500 pounds, of which 1250 pounds were allocated for the warhead. The warhead itself could have a maximum length of 65 inches.

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Warhead installation flights would start in April 1958, final systems demonstration of

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The Assistant Secretary of Defense notified the United States Atomic Energy Commission, October 10, 1958, that some time had passed since the Joint Chiefs of Staff had established a military requirement for a nuclear warhead for SERGEANT, but that a request for warhead development had been delayed pending a decision on the missile system itself.

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The Army would be the cognizant agent for the Department of Defense portion of the development, with normal Armed Forces Special Weapons Project participation.[13]

A Joint AEC/DOD Warhead Committee for SERGEANT was appointed and held its first meeting November 17, 1958. It was noted that the missile was in an advanced state of development and it appeared likely that the warhead flight-test program could proceed without major interruptions.

It was reported that considerable work had been accomplished on the missile fuzing system, but this had been designed to meet TX-43 requirements and might not be entirely applicable. There would be two options, air burst and contact burst, but no contact backup for the air-burst option. The fuze would be baro-armed and radar-fired in the air-burst option. Both impact crystals and crush switches would be considered for contact fuzing. At an altitude of 18,500 feet above the firing altitude, a baro offset switch would interrogate an arming-decision device to determine whether it was safe to arm the warhead. If trajectory and attitude were within limits, arming and firing signals would be generated in proper sequence.[14]

A SERGEANT meeting was held December 11-12, 1958. There was general agreement by all except Picatinny that a self-destruct feature was not desired. Development time scales were felt reasonable, with the exception of early flight-test dates which might be difficult to meet. The warhead would be design released in May 1960, with early production in May 1961, and would achieve operational capability in August 1961. Sandia proposed that a chopper-converter system be used. This would be a two-channel system, each channel of which would require a separate arming and charging signal. It was felt that a trajectory sensing or goof-proof device should be included, to provide ground handling safety.[15]

Sandia notified Albuquerque Operations Office, January 19, 1959, that it appeared entirely feasible to develop a warhead for the SERGEANT by August 1961, but that no firm commitment would be made until military characteristics had been received and evaluated.

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Military characteristics for the XW-52/SERGEANT were approved by the Military Liaison Committee January 20, 1959.

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Development authorization was released February 27, 1959.[18]

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Sandia forwarded the development program definition of the warhead to Albuquerque Operations Office April 22, 1959.

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Power would be supplied by the missile adaption kit. Sandia felt that the military characteristics required certain features that might limit use of the warhead for other applications or might compromise reliability, or were more appropriately adaption-kit requirements, and recommended changes were being discussed.[21]

Sandia wrote to the Division of Military Application April 29, 1959, commenting on the military characteristics. These characteristics had been prepared especially for the SERGEANT warhead, but it was felt that the size, shape and weight of the warhead should be optimized for other possible applications.[22]

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Since the missile system would not arm the warhead until the missile had entered the intended target area, there appeared to be no portion of the trajectory during which the proposed self-destruct system would be useful, and it was suggested that this requirement be deleted.

The option of air burst with contact preclusion was unclear, as both fuze and warhead attributes were involved, and contact-burst preclusion could be accomplished by the fuze. Since the warhead contained no energy source, it would be electrically inert and could be protected against accidental inputs by a handling safety device. This device would interrupt the power line from the adaption kit to the warhead and thus should be part of the Army's adaption kit. The warhead would have inaccessible trajectory-sensing devices, such as integrating accelerometers, and it was felt that caps that could be locked would provide no more safety than the use of caps having safety seals.[23]

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The higher yield weapon would have a maximum length of 65 inches and weigh not over 1200 pounds.[24]

Field Command notified Sandia January 9, 1961 that Report SC4445(WD), Proposed Ordnance Characteristics for the XW-52-X1 Warhead, had been reviewed in coordination with representatives of the interested Services. This review established that the design met all requirements of the military characteristics, with two exceptions. There was no provision for integral shielding against neutron radiation, but this had been accepted by the Army. Capability of monitoring the safe condition of the environmental sensing device would depend on current negotiations with the Army. The report had been accepted by the Design Review and Acceptance Group and was subsequently forwarded to the Division of Military Application.[32,33]

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The first XW-52-X1 Warhead tested was flown at the White Sands Missile Range March 10, 1961. The trajectory was low and the impact point about a kilometer short of the intended target.[35] Following this, three successful flights were staged in May 1961, and the balance of two flights was delayed pending availability of missiles.[36] These two flights were held in October 1961 and were successful.[37,38]

Static and centrifuge tests had meanwhile shown that the warhead design was more than adequate, and structural evaluation noted that the design could successfully withstand all handling and transportation loads, as well as carriage in the SERGEANT missile.[39] Engineering release of the Mk 52 Mod 1/SERGEANT was accomplished June 1961 on schedule, and early production achieved May 1962.

The Mk 52 Mod 2 Warhead was released January 28, 1963. This differed from the Mk 52 Mod 1 in that it incorporated a prescribed-action-link device, and entered production in February 1963.[40]

Sandia forwarded SC4715(WD), Final Report for the Mk 52 Mod 1 Warhead, to the Division of Military Application March 5, 1963. The report had been presented to and accepted by the Design Review and Acceptance Group. The warhead diameter was 24 inches, length 56.72 inches, and weight 925 pounds.

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Timetable of Mk 53 Events

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9/2/58 Division of Military Application requests estimate of operational availability date.

10/15/58 Los Alamos and Sandia submit tentative development schedule.

(b)(3)

6/17/59 Sandia forwards development program definition of TX-53 to the Albuquerque Operations Office.

(b)(3)

10/21/59 Proposed ordnance characteristics of TX-53 accepted by the Special Weapons Development Board.

3/13/60 Study of an XW-53/TITAN Warhead published.

5/17/60 Director of Defense Research and Engineering requests Atomic Energy Commission to participate in feasibility study of warheads for TITAN II missile.

7/12/60 Warhead feasibility study recommends development of an XW-53 Warhead for TITAN.

9/1/60 Director of Defense Research and Engineering requests Atomic Energy Commission to develop XW-53 Warhead.

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History of the Mk 53 Weapon

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This device pointed the way to development of the Mk 53.

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Subsequently, the Division of Military Application wrote to Albuquerque Operations Office, September 2, 1958, requesting that preliminary arrangements be made, but stating that full authorization would not be released until the military characteristics had been issued by the Department of Defense.[4] An estimated operational availability date was requested.[5]

The Los Alamos Scientific Laboratory and Sandia submitted a tentative development schedule October 15, 1958.

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Los Alamos and Sandia held a joint meeting November 13, 1958. The bomb would be carried in B-47 and B-52 aircraft, with possible application to the B-58 Pod and perhaps even to the B-70. However, the high speed of the B-70 would create high bomb-bay temperatures, and it was felt that this might seriously affect such items

as the parachute and the high explosive used in the design.[7] Various cooling methods were considered, including insulation of bomb-bay walls, use of a jettisonable water jacket, or filling the bomb bay with a low-density material blown in after the weapon had been loaded in the strike aircraft. It was noted that the bomb dimensions were limited by the size of the B-47 bomb bay and that redesign or repackaging of some weapon components might be necessary.[8]

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Sandia studied several possible ways of stabilizing the bomb in flight. Fin deployment appeared necessary for a number of reasons. There was an adverse center-of-gravity location, and the aircraft bomb bay limited the fin height. Aerodynamic requirements required stabilization of the bomb shortly after release, and it was felt that a large fin area would be needed. It would be necessary to provide mechanical devices between the fins to make sure that all four fins deployed simultaneously.[10]

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Sandia forwarded the TX-53 development program definition to Albuquerque Operations Office June 17, 1959.

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Delivery methods for the B-58 Two-Component Pod, recently redesignated the BLU-2/B Pod, would include high-altitude free fall and possibly low-level pop-up. Use of the bomb less parachute container and fins as a laydown device in an MB-1-type Pod would also be considered.

The Department of Defense would provide a parachute, and the Atomic Energy Commission would be responsible for nuclear design and the rest of the bomb. Units furnished for the B-58 Pod application would contain complete fuzing and firing systems, with the exception of pressure-sensing and contact-fuzing devices supplied by the Air Force. Sandia would provide the engineering and production specifications for all other fuzing components and materials.

The program schedule would depend on successful development of materials for mitigating high shock, high-strength light materials for secondary nuclear component support, and high-strength aluminum for the weapon case. The aerodynamic shape would have extendible fins to provide proper stability of free-fall bombs released at high altitudes.

The B-70 bomb application would be sufficiently unique to require a field modification kit to provide the required aerodynamic and heat-resistant qualities. This kit would be design released after compatibility had been proven in flights and drops from B-70 aircraft, but it was predicted that such aircraft would not be available until about mid-1962.

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Since the deformation switch used to produce contact firing signals in the complete bomb was different than the corresponding components in the Pod application, a connector was provided on the weapon skin to allow either type of deformation switch to be used.

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On July 15, 1959, the Air Force proposed that Sandia be responsible for providing pressure-sensing and contact-fuzing devices, rather than the Military, and this proposal was subsequently accepted by the Military Liaison Committee.[19]

An amendment to the military characteristics was issued August 4, 1959.

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A ballistic drop test was held September 12, 1959, and indicated need for modification of the low-level deployment sequence.

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The Air Force Special Weapons Center had requested a list of changes that would have to be made to provide a fuzing and firing system compatible with the low-level Special Weapons Emergency Separation System.

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Field Command wrote to the Air Force Special Weapons Center October 5, 1959, proposing that the variable timer for the laydown option be replaced with a single fixed time delay. This change would provide increased reliabiltiy and safety by eliminating the setting mechanism and the human effort involved in making the setting, and environmental protection would be increased, since the case would not have to provide a seal around the rotary shaft of the variable timer.[23] The Center replied October 16, 1959, noting that the Strategic Air Command had been queried, and a preference stated for the variable timer.[20]

Report SC4267(TR), Proposed Ordnance Characteristics of the Basic TX-53 and the TX-53 Bomb, was presented by Sandia to the October 21, 1959 meeting of the Special Weapons Development Board.[24] This noted that the Basic TX-53 would contain a

high-explosive implosion system, nuclear pit, gas-boosting system, secondary, electrical fuzing and firing system, primary case and Basic TX-53 case. The TX-53 Bomb would consist of the Basic TX-53, aft assembly with retardation parachute, extendible fins, shock-mitigating material, and nose assembly with impact switch.[3] The report was accepted and forwarded to the Division of Military Application December 4, 1959.[25]

Sandia had informed the Division of Military Application that the bomb would have to be thermally protected when carried in the B-70 aircraft, to maintain the bomb temperature below 165°F. This protection could be provided by bomb-bay cooling or insulation. Any modification to the bomb to provide the shock-mitigation system, afterbody or parachute with materials which could resist high temperatures would require at least 15 months of effort and would increase the weapon diameter to 52 inches, the length to 164 inches, and the weight to 9300 pounds.[26] Subsequently, December 10, 1959, the Air Force requested that any work toward establishing compatibility of the TX-53 Bomb with B-70 aircraft be halted, due to delays in the latter program.[19]

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Sandia informed the Air Force Special Weapons Center that the TX-53 Bomb experienced severe pitchdown in drop tests made from B-47 aircraft. This caused parachute deployment problems, imposed high aerodynamic loads on the bomb, and increased the

possibility of contact between bomb and aircraft during weapon releases. Separation from B-52 aircraft appeared satisfactory.[30]

The Center replied February 8, 1960, noting that the B-47 bomb bay had caused problems in the past, but that this had not prevented designers from achieving weapon compatibility without modifying the bomb bay. This latter work would require extensive aircraft modification and probably result in performance degradation. It was noted that there appeared to be close correlation between delivery speeds and weapon release characteristics. Since the B-52 was being modified to permit low-level flight at 400 knots, it was requested that separation tests of bomb from B-47 at this speed be conducted.[31]

Sandia notified Field Command February 16, 1960 that the design intent of the TX-53 was to ensure that fuzing-system restrictions on the bomb release altitude were less severe than limitations imposed by safe escape or other criteria. It was felt that, except for a minor altitude restriction for some retarded contact bursts, this design intent appeared to have been met. The fuzing system thus appeared to provide the necessary flexibility for the intended use of the bomb, and formal concurrence in the design was requested.[32] Field Command subsequently replied, noting that the Strategic Air Command stated that the release capabilities of the TX-53 Bomb were acceptable.[33]

Laydown tests demonstrated that the terminal velocity of the TX-53 Bomb was less than anticipated, and a change to the nose design was made which reduced the overall length of the bomb and provided better clearance in the B-47 bomb bay. It now became possible to jettison the parachute and its container in the free-fall option, and this change shifted the weapon center of gravity far enough forward so that aerodynamic stability was attained without deployable fins.[34]

A study of a warhead to be carried by the TITAN missile was reported March 13, 1960. This called for use of a high-yield warhead at ranges up to 5500 nautical miles, and a lighter weight warhead for targets 8500 miles distant. The XW-38 Warhead was being developed for application to the TITAN and ATLAS missiles for the latter usage, and consideration was given to the TX-53 design for the shorter

range, higher yield employment. The warhead could be severely reduced in weight over the bomb application, as the impact-mitigation system would not be needed.[35]

On May 17, 1960 the Director of Defense Research and Engineering requested the Atomic Energy Commission to participate in a feasibility study of warheads to be used with the TITAN II or SM-68B intercontinental ballistic missile system.

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The study report was published July 12, 1960, and recommended development of an XW-53 Warhead.

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The TITAN missile operational date was March 1963 and it was felt that the warhead could be provided at the same time. It was noted that if production authorization were received in the near future, flight tests could be started by November 1961, design release made in the same month, and early production achieved by December 1962.[37]

The Director of Defense Research and Engineering requested the Atomic Energy Commission, September 1, 1960, to proceed with development of the XW-53 Warhead, with the Air Force being designated cognizant agency for the Department of Defense, and normal Defense Atomic Support Agency participation.[38]

The military characteristics for the TITAN warhead were approved by the Military Liaison Committee October 18, 1960. Fuzing options included air burst with contact backup and contact burst.

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Sandia wrote to Albuquerque Operations Office March 10, 1961, discussing the development program definition for the XW-53. Sandia would be responsible for design and production specifications of the warhead, with the exception of explosive and nuclear parts. General Electric would develop the re-entry vehicle, and Glenn L. Martin Company would be in charge of missile development. Warhead design release would be in April 1962 with early production in January 1963.

per second. A disreefed 48-foot, three-parachute cluster replaced a 44-foot cluster.

The Air Force decided to provide the three 48-foot parachutes with a 22-1/2 foot reefing line and a 1-second reefing time. This resulted in an overload on the second parachute stage. To reduce this load and to move some of it to the first stage, the reefing-line length was increased to 25 feet. This design functioned satisfactorily, but the loads extrapolated to an overly high figure for the maximum drop conditions of the bomb. Sandia dropped a unit and found that two of the three parachutes failed completely by breaking the suspension lines.[41]

Sandia notified the Division of Military Application May 12, 1961, that the bomb production date would have to be delayed due to lack of a satisfactory retardation system. The Division of Military Application requested that another program assessment be made after drops scheduled for early June 1961.[42]

A meeting was held June 27, 1961 to discuss the results of the BLU-2/B drop-tower and laydown programs. There had been wide variation in test results, although drop conditions had been kept relatively constant. It appeared that the angle of impact significantly affected impact accelerations, and it was decided that the rest of the drop-tower program would be delayed until enough laydown tests had been completed to determine whether the drop-tower velocities were realistic.[43] Subsequently, Sandia reported, August 8, 1961, that 10 drop tests had been made of a half-scale beer-barrel nose. Results showed that the nose was capable of reducing the longitudinal impact acceleration to less than 100 g's.[44]

The Air Force Special Weapons Center notified Albuquerque Operations Office November 30, 1961, that the parachute was compatible with the TX-53 Bomb as carried in B-47 and B-52 aircraft.

(b)(1), (b)(3)

Field Command notified Sandia January 23, 1962, that Report SC4553(WD), Proposed Ordnance Characteristics for the XW-53 Warhead, had been reviewed in coordination with representatives of the interested Services. The review established that the design met all the requirements of the approved military characteristics, with certain exceptions.

The diameter of 40.5 inches over the mounting flange exceeded the 37.5 inches allowed by the military characteristics, but this was acceptable, as was the warhead length of 103.5 inches rather than the desired 102 inches. It was felt that considerable increase in safety could be realized if the environmental sensing device were upgraded to minimize the possibility of its being inadvertently operated or bypassed in a fire environment, and it was requested that efforts be directed toward such improvement.

(b)(1), (b)(3)

Otherwise, the design was acceptable to the Department of Defense.[46]

Sandia wrote to Albuquerque Operations Office January 31, 1962, noting that a proposed acceleration of the XW-53 Warhead design, with release in October 1962 rather than February 1963, would require issuance of information considered premature even for the later date. Deliveries of development hardware had been delayed and there were progressive slippages in the flight-test program. However, every attempt would be made to provide certified production material by the date requested and, if not, operative components would be made available.[47]

Field Command notified Sandia February 13, 1962, that Report SC4621(WD), Interim Development Report for the TX-53 Basic Assembly and TX-53 Bomb, had been reviewed in coordination with representatives of the interested Services. There were a few deviations from the military characteristics. There was no warhead entity as such, but the basic assembly included the warhead elements, as well as all fuzing and firing components except the impact-fuzing or deformation switch, and this deviation was acceptable.

(b)(1), (b)(3)

Effective length of the TX-53 was 148.75 inches to the rear automatic deployment cover, slightly more than desired, but this length was compatible with designated carriers and was acceptable. The weight was 8850 pounds, slightly more than specified, and this also was acceptable.

(b)(1), (b)(3)

This latter capability would be provided at a later date.

(b)(1), (b)(3)

Sandia subsequently notified Field Command May 10, 1962, that the Mk 53 had three power sources; aircraft monitor and control system, fast-rise thermal batteries, and main-fuzing-system thermal batteries. The electrical system of the bomb had been designed so that the firing-system circuits were physically separated from any circuits likely to receive power in the event of fire. It was thus felt that the bomb provided sufficient fire safety, but thermal fuses would be included in the fuzing-system selector control as an added safeguard.[49]

The Mk 53 Bomb and the Mk 53 Basic Assembly were design-released August 10, 1962. It was noted that the B-47 bomb-bay spoiler doors had to be retracted for both high- and low-altitude releases to prevent adverse bomb pitchdown at release.[50]

(b)(1), (b)(3)

switch had to be manually turned to the ARMED position (either retard or free fall) before takeoff, or a weapon dud would result. The fuzing-system control selector provided choice of air or contact burst. Laydown delayed burst was automatically selected when the bomb was released below its specified altitude, with the aircraft monitor and control selector placed at AIR or GROUND.

When the bomb was released from the carrying aircraft, pullout rods were extracted, and this action activated pulse generators which initiated fast-rise thermal batteries and a set of sequential timers. The batteries supplied power to baroswitch and timers, and activated another set of thermal batteries.

(b)(1), (b)(3)

About one second after weapon release, sequential-timer contacts closed and completed circuits between battery pack and detonators in the automatic parachute deployment system. At the same time, the timer provided a signal that severed the retardation-parachute suspension lines, and the following deployment sequence occurred: The automatic deployment cover was separated from the rear case section by the explosion of a length of mild detonating fuse, the cover deployed a 4-foot-diameter pilot chute, the pilot chute deployed a 16.5-foot ribbon retardation chute permanently reefed to 12 feet, and the retardation chute deployed the laydown parachute system, which consisted of three 48-foot ribbon chutes, each reefed to 22.5 feet for 2 seconds after line stretch.

The laydown parachute system was designed to reduce the rate of fall of the bomb to less than 55 feet per second, and to position the bomb upright at the instant of impact. The energy of impact was absorbed by aluminum honeycomb in the bomb nose. Since strong surface winds might cause the bomb to fall over on its side, similar shock-absorbing material was placed around the bomb components.

As the rotary switch remained in the laydown option in low-altitude releases, main battery power was supplied to the laydown bus after bomb release. Retardation created by the laydown parachute caused an interval timer to operate toward its armed position, applying main battery power to the motor and contacts of the sequential timer.

(b)(1), (b)(3)

At detonation time a third switch closed, activating explosive switches and triggering the spark gap to cause bomb detonation.

(b)(1), (b)(3)

Less than one second after bomb release, the rotary switch turned to the high-level option position. Shortly afterward, the sequential timer completed a circuit between battery pack and detonators in the automatic parachute deployment system. If free-fall option had been selected, closure of contacts in the sequential timer applied power from fast-rise thermal batteries to parachute deployment system and severed the chute attachments, allowing the retardation chute to extract and discard the laydown parachute in its stowage can. If the retarded option had been selected, the sequence was similar to that for free fall, except that the parachute deployment proceeded normally.

Air-burst option could be selected by the aircraft monitor and control system.

(b)(3)

(b)(1), (b)(3)

Less than 1 second after weapon release, the option switch operated to the high-altitude option. Closure of a timer 1 second after release had no effect on Pod operation.

(b)(3)

If contact option had been selected on the Warhead Control Selector Switch before release, the fire baro was bypassed and the Pod contact crush switch was brought into the circuit. The firing pulse transformer circuit was completed by the impact crush switch which closed on impact with the target.[60]

(b)(1), (b)(3)

Report SC-WD-64-574, Final Development Report for the Mk 53 Mod 0 Warhead, was issued by Sandia in December 1965. This noted that the warhead system used a rotary chopper/converter system to change low-voltage direct current at about 28 volts to about 2100 volts direct current. An environment similar to the launch acceleration of the TITAN II missile had to be experienced to complete the converter arming circuit. This acceleration operated the environmental sensing device.

When two independent arming signals were applied to both chopper and converter, the applied voltage was chopped, transformed, rectified and used to charge the X-unit capacitor bank and arm the trigger circuit.

(b)(3)

Detonation of an armed warhead could be accomplished by either a low-voltage (17 volts) or high-voltage (250 volts) method. The output of the trigger circuit was applied to one probe of the dual-probe spark gap. This signal caused ionization of the spark gap, and energy stored in the X-unit capacitor bank was transferred to the detonators, causing detonation of the warhead. Energy from the capacitor bank also triggered an explosive timer on the neutron generators. This timer burned down and detonated the explosive driver which depoled a ceramic crystal. The crystal then supplied a high-voltage pulse to a deuterium-tritium tube which provided neutrons for initiation.[62]

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AEC ATOMIC WEAPON DATA

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HISTORY OF THE MK 52 WARHEAD (U)

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Weapon Systems

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Redacted Version

Information Research Division, 3434

Classified By: Richard B. Craner
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History of the Mk 52 Warhead

The Mk 52 resulted from the effort to provide the Army SERGEANT rocket with an appropriate nuclear warhead. An early meeting was held September 25, 1953, with representatives of the missile contractor (the Jet Propulsion Laboratory of the California Institute of Technology), the Armed Forces Special Weapons Project and Sandia in attendance. It was noted that the SERGEANT would be 30 inches in diameter, 35 feet long, weigh 10,000 pounds, and be able to carry a 1500-pound warhead to a range of 75 to 100 miles. The SERGEANT was a surface-to-surface, solid-propellant guided rocket, intended as a replacement for the CORPORAL, which carried a Mk 7 Warhead.[1]

The Division of Military Application, in a letter dated November 27, 1953, noted that the SERGEANT had not yet been approved as an atomic weapon carrier, and that Sandia participation should be limited to liaison and interchange of information to assist the Jet Propulsion Laboratory in preparing a system proposal.[2]

Little immediate warhead work was performed, but by late May 1955 Sandia studies indicated that it would be possible to provide a warhead to meet missile requirements of reliability, simplicity, ease of operation, freedom from countermeasures, ruggedness and safety. A thermonuclear design was suggested, since the higher yield and efficiency of such weapon would have size and weight advantages that would aid in achieving missile objectives.[3]

The Assistant Secretary of Defense notified the United States Atomic Energy Commission August 29, 1955 that early production of the SERGEANT missile was scheduled for May 1959. Request was made for participation in a joint feasibility study of suitable warheads for the system, in cooperation with the Army and the Armed Forces Special Weapons Project, and this request was subsequently forwarded to both Santa Fe and San Francisco Operations Offices.[4]

By mid-April 1956, two successful SERGEANT flight tests had taken place. The rocket was inertially guided, and continuous guidance correction during the missile flight

was provided. The range was controlled by extending the drag brakes of the missile for a specified length of time.

(b)(1), (b)(3)

The Army's Picatinny Arsenal had been studying possible fuzing systems and proposed that a radiating-type fuze be used, with options of air burst with contact backup, ground burst, and air burst with contact preclusion. It was felt that either inertial or barometric fuzing would not be sufficiently precise, as it was hoped to develop a burst-height accuracy of ±50 feet.

(b)(3)

A feasibility study group had meanwhile been formed, with representatives from Field Command, Picatinny Arsenal and Sandia. This group reported, July 25, 1956, that it would be about a year and a half before firm atomic-warhead information would be required for the SERGEANT program, and that consideration of warhead designs was premature. It was proposed that warhead selection, as well as completion of the feasibility study, be deferred until after the 1957 nuclear test series.[6]

Picatinny Arsenal requested information on the one-point-detonation characteristics of the nuclear design, so that an adequate safing system could be devised.

(b)(1), (b)(3)

Rocket design continued, with little work being done on the warhead. The feasibility study group again met December 3-4, 1957, and learned that the rocket operational availability date of mid-1962 might be shortened by almost a year.

(b)(1), (b)(3)

(b)(1), (b)(3)

Picatinny Arsenal released the feasibility study report December 31. 1957.

(b)(1), (b)(3)

Typical targets were fighter airfields, command posts, headquarters, communication centers, supply and logistic installations, troop units, tanks and artillery.

The rocket was 31 inches in diameter, 31 feet long, and weighed 10,000 pounds at launch. It was composed of four major sections; propulsion, fins, guidance and warhead. The solid-propellant motor had a burning time of 28 seconds and reached a peak longitudinal acceleration of about 10 g's at burnout. The range was controlled by four simultaneously activated drag brakes which extended and retracted three times during the upward leg of the missile trajectory. The time that the brakes remained extended was determined by an internal computer which continuously compared the actual position and velocity of the rocket, as determined by an inertial platform, with the reference trajectory that the missile should be following for that particular range.

Time of flight varied between 120 and 200 seconds. About 22 seconds prior to impact, an arming decision was made, based on establishment of the square or window in space through which the missile would have to pass in order to receive an affirmative arming command. During the final 20 seconds of flight any necessary corrective maneuvers were performed.

The nose section for the warhead would have an overall length of 139 inches, with the base of the section having a diameter of 31 inches and tapering to a point. The warhead installation would be limited to a weight of 1500 pounds, of which 1250 pounds were allocated for the warhead. The warhead itself could have a maximum length of 65 inches.

(b)(1), (b)(3)

Warhead installation flights would start in April 1958, final systems demonstration of

(b)(1), (b)(3)

The Assistant Secretary of Defense notified the United States Atomic Energy Commission, October 10, 1958, that some time had passed since the Joint Chiefs of Staff had established a military requirement for a nuclear warhead for SERGEANT, but that a request for warhead development had been delayed pending a decision on the missile system itself.

(b)(1), (b)(2), (b)(3)

The Army would be the cognizant agent for the Department of Defense portion of the development, with normal Armed Forces Special Weapons Project participation.[13]

A Joint AEC/DOD Warhead Committee for SERGEANT was appointed and held its first meeting November 17, 1958. It was noted that the missile was in an advanced state of development and it appeared likely that the warhead flight-test program could proceed without major interruptions.

It was reported that considerable work had been accomplished on the missile fuzing system, but this had been designed to meet TX-43 requirements and might not be entirely applicable. There would be two options, air burst and contact burst, but no contact backup for the air-burst option. The fuze would be baro-armed and radar-fired in the air-burst option. Both impact crystals and crush switches would be considered for contact fuzing. At an altitude of 18,500 feet above the firing altitude, a baro offset switch would interrogate an arming-decision device to determine whether it was safe to arm the warhead. If trajectory and attitude were within limits, arming and firing signals would be generated in proper sequence.[14]

A SERGEANT meeting was held December 11-12, 1958. There was general agreement by all except Picatinny that a self-destruct feature was not desired. Development time scales were felt reasonable, with the exception of early flight-test dates which might be difficult to meet. The warhead would be design released in May 1960, with early production in May 1961, and would achieve operational capability in August 1961. Sandia proposed that a chopper-converter system be used. This would be a two-channel system, each channel of which would require a separate arming and charging signal. It was felt that a trajectory sensing or goof-proof device should be included, to provide ground handling safety.[15]

Sandia notified Albuquerque Operations Office, January 19, 1959, that it appeared entirely feasible to develop a warhead for the SERGEANT by August 1961, but that no firm commitment would be made until military characteristics had been received and evaluated.

(b)(1), (b)(3)

Military characteristics for the XW-52/SERGEANT were approved by the Military Liaison Committee January 20, 1959.

(b)(1), (b)(3)

Development authorization was released February 27, 1959.[18]

(b)(1), (b)(3)

Sandia forwarded the development program definition of the warhead to Albuquerque Operations Office April 22, 1959.

(b)(1), (b)(3)

Power would be supplied by the missile adaption kit. Sandia felt that the military characteristics required certain features that might limit use of the warhead for other applications or might compromise reliability, or were more appropriately adaption-kit requirements, and recommended changes were being discussed.[21]

Sandia wrote to the Division of Military Application April 29, 1959, commenting on the military characteristics. These characteristics had been prepared especially for the SERGEANT warhead, but it was felt that the size, shape and weight of the warhead should be optimized for other possible applications.[22]

(b)(3)

Since the missile system would not arm the warhead until the missile had entered the intended target area, there appeared to be no portion of the trajectory during which the proposed self-destruct system would be useful, and it was suggested that this requirement be deleted.

The option of air burst with contact preclusion was unclear, as both fuze and warhead attributes were involved, and contact-burst preclusion could be accomplished by the fuze. Since the warhead contained no energy source, it would be electrically inert and could be protected against accidental inputs by a handling safety device. This device would interrupt the power line from the adaption kit to the warhead and thus should be part of the Army's adaption kit. The warhead would have inaccessible trajectory-sensing devices, such as integrating accelerometers, and it was felt that caps that could be locked would provide no more safety than the use of caps having safety seals.[23]

(b)(1), (b)(3)

The higher yield weapon would have a maximum length of 65 inches and weigh not over 1200 pounds.[24]

Field Command notified Sandia January 9, 1961 that Report SC4445(WD), Proposed Ordnance Characteristics for the XW-52-X1 Warhead, had been reviewed in coordination with representatives of the interested Services. This review established that the design met all requirements of the military characteristics, with two exceptions. There was no provision for integral shielding against neutron radiation, but this had been accepted by the Army. Capability of monitoring the safe condition of the environmental sensing device would depend on current negotiations with the Army. The report had been accepted by the Design Review and Acceptance Group and was subsequently forwarded to the Division of Military Application.[32,33]

(b)(1), (b)(3)

The first XW-52-X1 Warhead tested was flown at the White Sands Missile Range March 10, 1961. The trajectory was low and the impact point about a kilometer short of the intended target.[35] Following this, three successful flights were staged in May 1961, and the balance of two flights was delayed pending availability of missiles.[36] These two flights were held in October 1961 and were successful.[37,38]

Static and centrifuge tests had meanwhile shown that the warhead design was more than adequate, and structural evaluation noted that the design could successfully withstand all handling and transportation loads, as well as carriage in the SERGEANT missile.[39] Engineering release of the Mk 52 Mod 1/SERGEANT was accomplished June 1961 on schedule, and early production achieved May 1962.

The Mk 52 Mod 2 Warhead was released January 28, 1963. This differed from the Mk 52 Mod 1 in that it incorporated a prescribed-action-link device, and entered production in February 1963.[40]

Sandia forwarded SC4715(WD), Final Report for the Mk 52 Mod 1 Warhead, to the Division of Military Application March 5, 1963. The report had been presented to and accepted by the Design Review and Acceptance Group. The warhead diameter was 24 inches, length 56.72 inches, and weight 925 pounds.

(b)(1), (b)(3)

DOE F 1325.8

United States Government

Department of Energy

Albuquerque Operations Office

memorandum

DATE: January 3, 1994

REPLY TO ATTN OF: NESD

SUBJECT: Nuclear Explosive Safety Study Report

TO: RADM Charles J. Beers, Jr., USN, Deputy Assistant Secretary for Military Application, DP-20, HQ

This memorandum is for Defense Programs' approval and signature for the attached safety study report.

I have reviewed the safety study report, "Nuclear Explosive Safety Study of B53 Mechanical Disassembly Operations at the USDOE Pantex Plant."

I concur that the studied operations are not a threat to nuclear explosive safety and meet the Nuclear Explosive Safety Standards a., b., c., and e. and other nuclear explosive safety criteria of DOE Order 5610.11; except that portion which has not been implemented, as specified in Appendix A; and of AL Supplemental Directive 5610.11. The recommendations in this study should be approved and implemented. Nuclear Explosive Safety Standard d. is evaluated by the Department of Energy (DOE) Albuquerque Operations Office, Security and Nuclear Safeguards Division's security surveys and DOE Headquarters' inspections and evaluations of Pantex Plant security operations. These surveys and inspection and evaluations verify that there are positive measures to ensure adequate security of nuclear explosives pursuant to the DOE safeguards and security requirements. Accordingly, I consider that Standard d. is met for the Pantex Plant.

I recommend approval of the attached safety study report.

Bruce G. Twining
Manager

Attachment (SRD)

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UNITED STATES
DEPARTMENT OF ENERGY
NUCLEAR EXPLOSIVE SAFETY STUDY GROUP

NUCLEAR EXPLOSIVE SAFETY STUDY OF B53 MECHANICAL DISASSEMBLY OPERATIONS AT THE USDOE PANTEX PLANT (U)

OCTOBER 1, 1993

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CLASSIFIED BY A. A. Nichols ORG. NESS
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NUCLEAR EXPLOSIVE SAFETY STUDY

OF

B53 MECHANICAL DISASSEMBLY OPERATIONS

AT THE

USDOE PANTEX PLANT (U)

The report has been approved by the following members of the Nuclear Explosive Safety Study Group:

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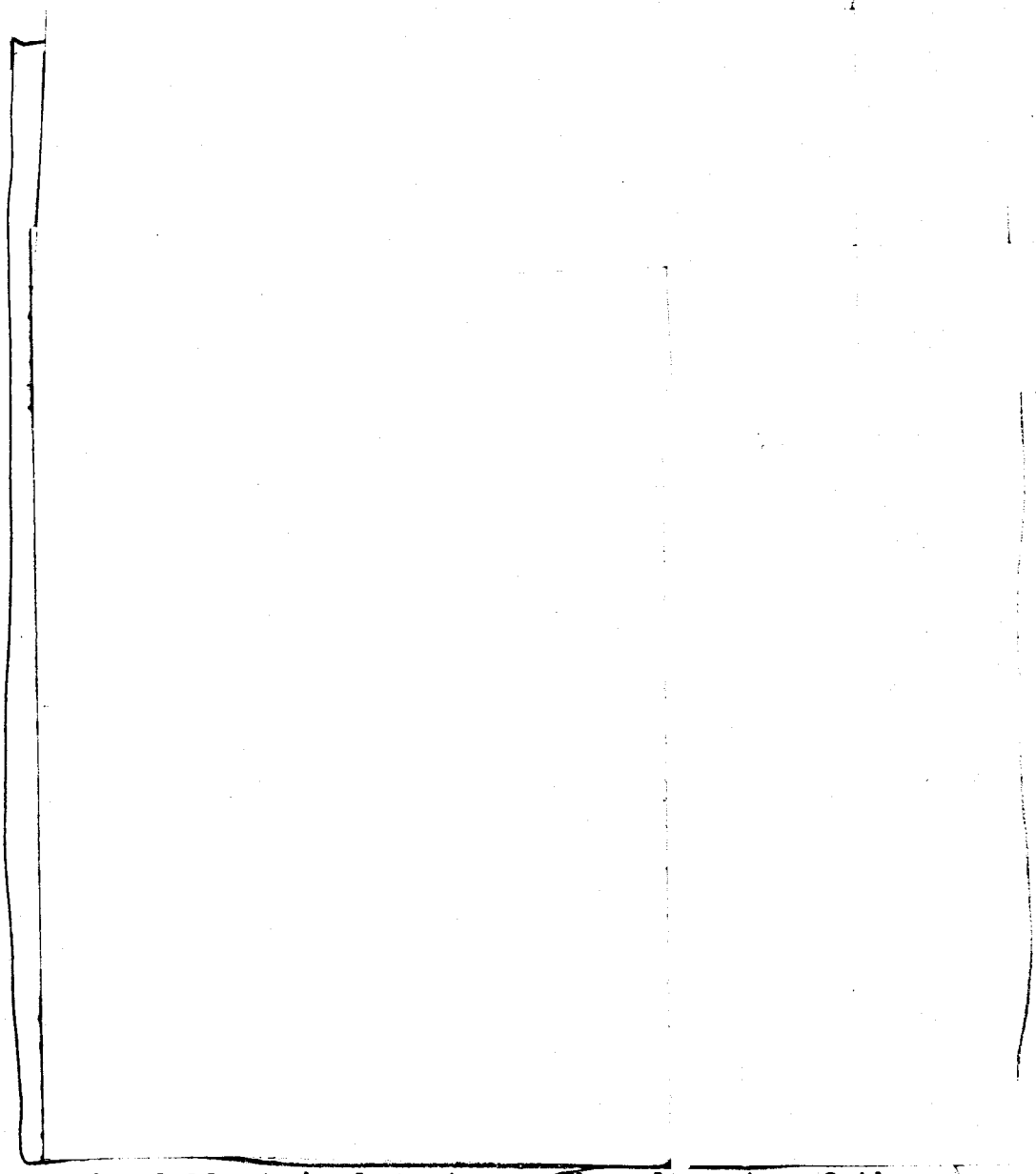
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B53 Warhead Electrical System. The elements of the B53 electrical system associated with the bomb firing system are the lightning arrestor connector (LAC), the MC4065 power pack, the MC1199 electrical system safing switch, two MC4066 neutron generators, the MC744B X-unit, two MC1262 fast-rise thermal batteries, and two MC1264 thermal batteries. The B53 bomb arming and firing system is dual-channel except for the capacitor bank, and the spark gap.

The LAC provides the electrical interface to external sources of electrical energy and in conjunction with the MC2969 strong-link switch protects against electrical energy from a lightning strike. The LAC is located at the bomb/pullout cable interface.

The MC4065 power pack contains a high voltage transverter, a trigger circuit, the neutron generator low voltage attenuator, and the MC2969 strong-link switch which are potted in a stainless steel housing. The MC2969 is enabled by a unique signal provided by a source external to the bomb. The MC2969 interrupts all electrical lines, except electrical ground, going into the firing set.

The MC1199 electrical system safing switch is manually operated and provides visual indication of the switch position (safe, retard, or free-fall). The handle of the MC1199 is mechanically locked in the safe position by a solenoid-operated pin. The MC1199 may be operated to

the safe position with or without power applied to the solenoid.

DOE b(3) C

Two MC1262 fast-rise thermal battery packs are used in the B53. The MC1262 is a two-section thermal battery containing a 12-volt fast-rise section and 28-volt power section.

Two MC1264 thermal batteries are used in the B53 to provide dual channel power for the fuzing system. The MC1264 is nominally a 28-volt battery with an activated life in excess of 240 seconds. It is activated by electrical power from the 12-volt section of the MC1262.

Nuclear Explosive Safety Theme. Although the B53 was not developed with modern design criteria, several abnormal environment nuclear explosive safety design features have been added to enhance nuclear explosive safety. The nuclear explosive safety theme of the B53 involves energy diversion through conductive metal barriers, exclusion of electrical energy into the firing set by a strong-link switch that is enabled by a unique signal, and location of the strong-link near the weak-links. A LAC is used at the bomb/pullout cable interface to provide protection against electrical energy to the bomb that could result from lightning strikes.

DOE b(3) C

[redacted] Also, all B53s in stockpile are inherently one-point safe.

S Permissive Action Link (PAL). The B53 does not have a PAL capability.

S Command Disable (CD). The B53 does not have a CD function.

Non-DOE Components. All components of the B53 are DOE's responsibility.

DOE b(3) C

[redacted]

Shipping Configuration. The H794 Hand Truck is a caster-mounted metal truck used for shipping, storage, positioning, and maneuvering of the B53. The H794 is approximately 10 feet long and 5 feet wide and weighs approximately 1000 pounds. The bomb is held in place by two aluminum bands and longitudinal movement is resisted by a telescoping steel shear pin.

Tiedown Specification for On-Site and Off-Site Transportation of the B53

Tiedown requirements for movement of the B53 at the Pantex Plant and over-the-road were reviewed by the NESSG. Sandia National Laboratories (SNL) provides the tiedown patterns used for on-site movement of nuclear explosives at the Pantex Plant. Tiedown requirements for over-the-road are provided to Mason & Hanger-Silas Mason Co., Inc. (M&H), through the Technical Publications 45-51 series. Test data and/or analysis used by SNL to determine tiedown patterns and tiedown materials used in the tiedown of B53 are available at Organization 9613, SNL, New Mexico, have been reviewed, and meet the criteria established in Reference B for on-site transportation and Reference E for over-the-road transportation.

Chemical Compatibility

The materials compatibility program conducted tests to ascertain continued safety of all nuclear explosives when subjected to chemical interactions between materials or chemical aging throughout the stockpile life. No increased safety risks due to chemical compatibility problems have been identified. Also, the explosive compatibility program shows that there are no incompatibilities with the materials and surroundings found at the Pantex Plant and the B53 HE.

HE Aging

Selected properties of Cyclotol and Composition B have been evaluated from aged stockpile materials and local testing. There are no signs of degradation from aging or incompatibility.

One-Point and Criticality Safety

Los Alamos National Laboratory (LANL) certifies that all B53s remaining in stockpile have been individually calculated to be inherently one-point safe.

S DOE 6(3)

[redacted]

LANL also certifies criticality safety, even in abnormal environments, provided only that the primary remains intact. Also, for as many as 10 undamaged B53s, there are no criticality concerns for any spacing/arrangement.

Response to Pantex Plant Abnormal Environments

Appendix B provides information about and the response of the B53 in configurations C and D to the identified and defined abnormal-environment threats at the Pantex Plant. The nuclear explosive safety design features of the B53, the Pantex Plant facilities where the B53 will be processed, and nuclear explosive safety controls and procedures in effect at the Pantex Plant combine to result in a predictably-safe response (no worse than a one-point detonation) to all identified and defined single and multiple abnormal-environment threats at the Pantex Plant for each configuration of the B53, except for tornado. The NESSG believes that an aircraft crash could also result in an unpredictable response. An unpredictable response would require the bomb center case to be breached, a compromised firing set, an appropriate energy source, and an intact primary. It is highly unlikely that a force strong enough to breach the bomb center case would leave the main charge detonators, high explosive, and pit undamaged. Additionally, the appropriate energy would have to be applied to more than one detonator simultaneously since the B53 is inherently one-point safe. The protection provided in Zone 4 and Zone 12 structures of the Pantex Plant, the nuclear explosive safety controls and procedures in effect for all nuclear explosive operations, and the rugged construction of the hardened trailers significantly reduce the threat to nuclear explosive safety of the abnormal environments. The NESSG believes that the possibility of the tornado or aircraft crash resulting in a threat to nuclear explosive safety is remote.

Reader-Worker Procedures and Checkoff Lists

Reader-worker procedures and checkoff lists are required and in use for those B53 mechanical disassembly operations requiring person-to-person coverage.

Additional Information

Additional information about the B53 and about the operations associated with the B53 is in Appendices B, C, and D.

Issues Resolved Without a Finding

1. A PT4118 multicircuit continuity tester is used to verify the safe position of the MC2969 strong-link switch before disassembly of the nuclear

explosive. The NESSG proposed that this test be performed only once after bomb return and that the test be performed in the Zone 12 disassembly bay. This action was agreed to by M&H and SNL. It shall be implemented prior to resuming B53 disassembly operations and the applicable operating procedures shall be revised by M&H and verified by DOE/Amarillo Area Office (AAO).

2. M&H and SNL proposed delaying removal of the protective shroud over the detonator cables to reduce the vulnerability of the nuclear explosive and thus the requirements for person-to-person coverage. The NESSG agrees with this proposal. Removal of the protective shroud shall occur as late as possible in the disassembly process. This change shall be implemented prior to resuming B53 disassembly operations and the applicable operating procedures shall be revised by M&H and verified by DOE/AAO.

3. M&H proposed to stage the end cap assembly (primary) in Zone 12 prior to its disassembly operations. Staging will be accomplished in a new stand that is similar to the old stand, but with provision for a totally enclosing metal cover and protective blankets. The NESSG agrees with this proposal. After receipt of this tooling and before resumption of B53 disassembly operations, the tooling shall be reviewed by Battelle Pantex/Nuclear Explosive Safety Division (NESD) and DOE/AAO/Nuclear Explosive Safety and approved by DOE/AL/NESD. Prior to resuming B53 disassembly operations, the applicable operating procedures shall be revised by M&H and verified by DOE/AAO.

Conclusions

The NESSG concluded that References A through G are valid, appropriate, and adequate and are applicable to the studied B53 operations. The NESSG also concluded that the procedures, equipment, and administrative controls to be employed with the studied operations are not a threat to nuclear explosive safety and meet Nuclear Explosive Safety Standards a., b., c., and e. and other nuclear explosive safety criteria of DOE Order 5610.11; except that portion which has not been implemented, as specified in Appendix A; and of AL Supplemental Directive 5610.11. Nuclear Explosive Safety Standard d. is evaluated by the DOE/AL, SNSD's security surveys and DOE Headquarters' inspection and evaluations of Pantex Plant security operations.

B. DOE/AL Master Tester List (MTL)

Discussion

The following tester is needed for B53 disassembly operations at the Pantex Plant:

Tester	Category	On MTL for other Programs	Analysis in Appendix B and Reference	Needed for Operations
PT4118	Blue	Yes	---	Yes

The application of the above listed tester to the B53 was reviewed. Appendix B contains the tester safety analysis summary and tester/nuclear explosive interface analysis for the PT4118 tester.

> The PT4118 multicircuit continuity tester is a blue decal tester used on the B53 system to verify the safe position of the MC2969 strong-link switch. The PT4118 is a hand held tester using a light emitting diode (LED) to indicate the continuity of an external circuit. It derives its electrical power from an internal mechanical hand crank generator. Two independent circuits can be checked at the same time. The PT4118 contains a mechanical voltage source, dual current limiters, dual voltage limiters, and two LED current monitors to indicate an external circuit continuity for two independent circuits. The external circuit is connected in series with the voltage source, current limiters, and LED. Continuity is indicated for circuits less than 4000 ohms. The PT4118 does not contain any stored energy sources (e.g., a battery). Lab testing of the PT4118 has revealed output currents of 0.5 to 0.75 amperes through an external load of 5 ohms. This is in the form of 100 nanosecond wide pulses randomly generated during operation of the hand crank generator. This technically violates the blue decal limit of 0.1 ampere. No critical circuit hazard exists because the energy deposition resulting from the 100 nanosecond current excursions is below the no-fire level of all electro-explosive devices within the nuclear explosive stockpile.

Conclusions

The NESSG concluded that the deviations from accepted design criteria by the PT4118 tester are of no consequence. The PT4118 tester is not a threat to

nuclear explosive safety when employed in the intended application for tests on the B53.

Recommendation AL MTL

The PT4118 be listed on the AL MTL for the B53.

Action

AL

C. Safety Rules and Immediate-Action Procedures

Discussion

The NESSG evaluated the proposed specific Safety Rule and immediate-action procedures to be used for B53 operations.

Conclusions

The proposed specific Safety Rule adequately covers B53 disassembly operations.

Specific immediate-action procedures (not All Other Programs) are required for B53 disassembly operations.

Recommendations - Safety Rules and Immediate-Action Procedures

1. Approve the B53 specific Safety Rule as follows:

   Upon bomb return, before disassembly operations are performed, the MC2969 strong-link switch shall be electrically monitored to verify the safe condition of the switch.

2. Approve the immediate-action procedures for the B53 as follows:

   a. No attempt should be made to move the nuclear explosive.

   b. Turn off and disconnect all test equipment from the nuclear explosive.

   c. Further operations (including disassembly) on the nuclear explosive are specifically prohibited.

APPENDIX A

DOE ORDER 5610.11 IMPLEMENTATION

There is a portion of DOE Order 5610.11 which has not been implemented and which is applicable to the "Nuclear Explosive Safety Study of B53 Mechanical Disassembly Operations at the USDOE Pantex Plant," dated October 1, 1993. This portion is applicable to the Department of Energy Albuquerque Operations Office.

Chapter IX; Risk Assessment. This chapter requires quantitative risk assessments for all onsite operations. The risk assessment program is being implemented; however, the risk assessment for the B53 has not been started at this time.

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I. SCOPE

The scope of this Nuclear Explosive Safety Study is limited to those operations performed during B53-1 disassembly for removal of parent unit parts to be used during Joint Test Assembly build. These operations include on and off-site transportation of the B53-1, disassembly of the B53-1 through removal of the firing set (power pack and X-unit) from the aft cap, reconstitution of the remaining material into a BA53-like assembly, and on-site transportation of the BA53 to storage. Specifically excluded from this study is disassembly of the nuclear system.

II. DESCRIPTIONS

A. General Description of Bomb

The B53-1 is a thermonuclear device, approximately 148 inches long and 50 inches in diameter weighing approximately 8850 pounds. It consists of a nuclear system and electrical system components. The bomb provides only a laydown option and is timer armed and fired. The bomb consists of a Basic Assembly (BA) and Basic Shape Components. A view of the shape components exploded away from the Basic Assembly BA is shown in Figure 1. The BA contains the nuclear system and the electrical component assembly.

C

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DOE b(3) C

The case of the BA is an aluminum structure that consists of two 1/2-inch thick cylindrical sections, a 1/2-inch thick conical section, two end caps, and a closure plate. The complete fuzing and firing electrical component assembly is contained in the BA between the aft end cap and the closure plate.

B. Nuclear Warhead Electrical System

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MC1178 Laydown Timer -- The MC1178 includes two electric motors (SA377) for operation of two separate channels. Each motor operates two SA833 snap-action switches at each of three time intervals. The switches are wired so that fuzing channels are switched by either timer motor. Fire signal times from 30 to 240 seconds, in 30-second increments, can be set into the MC1178 with a

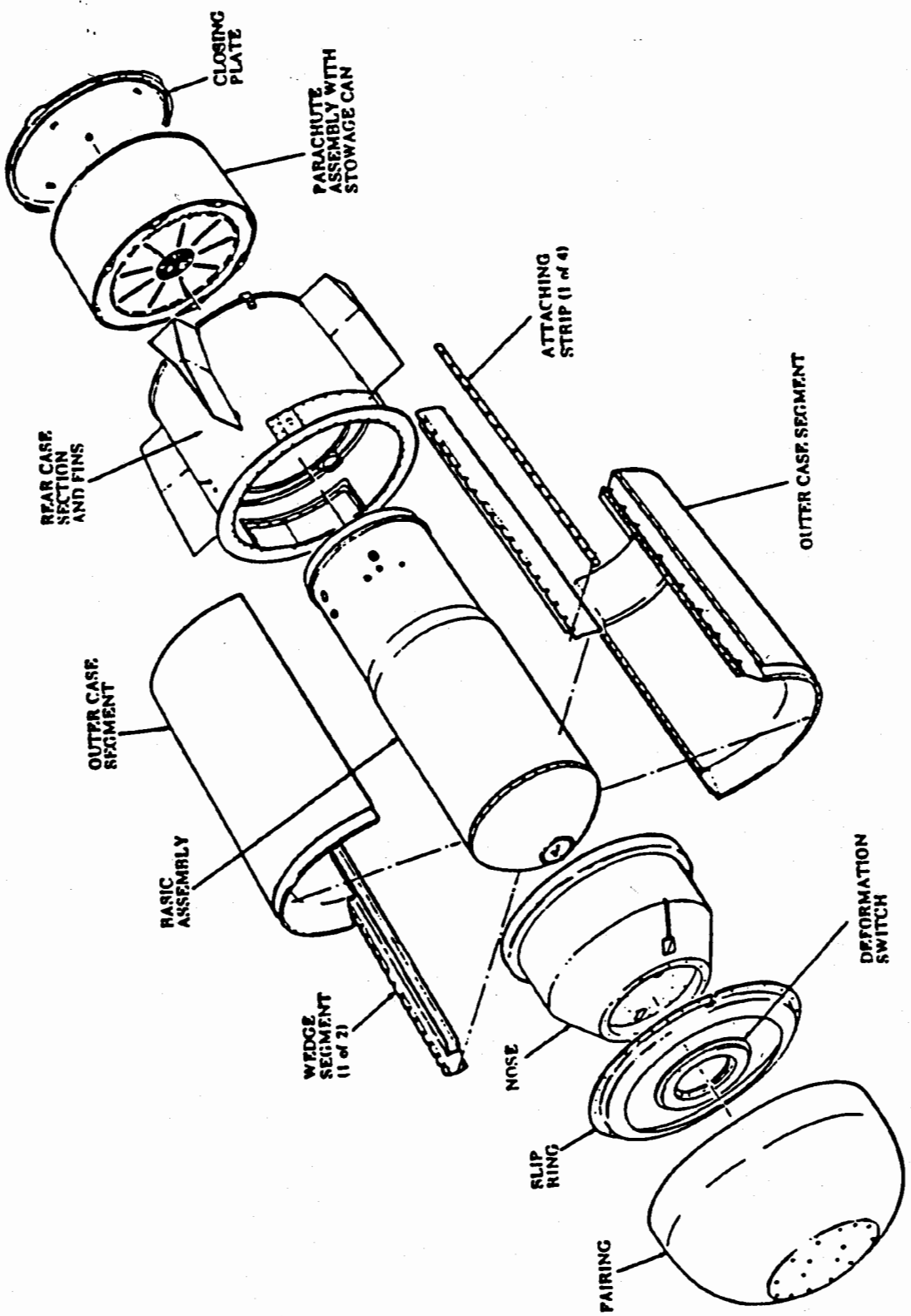
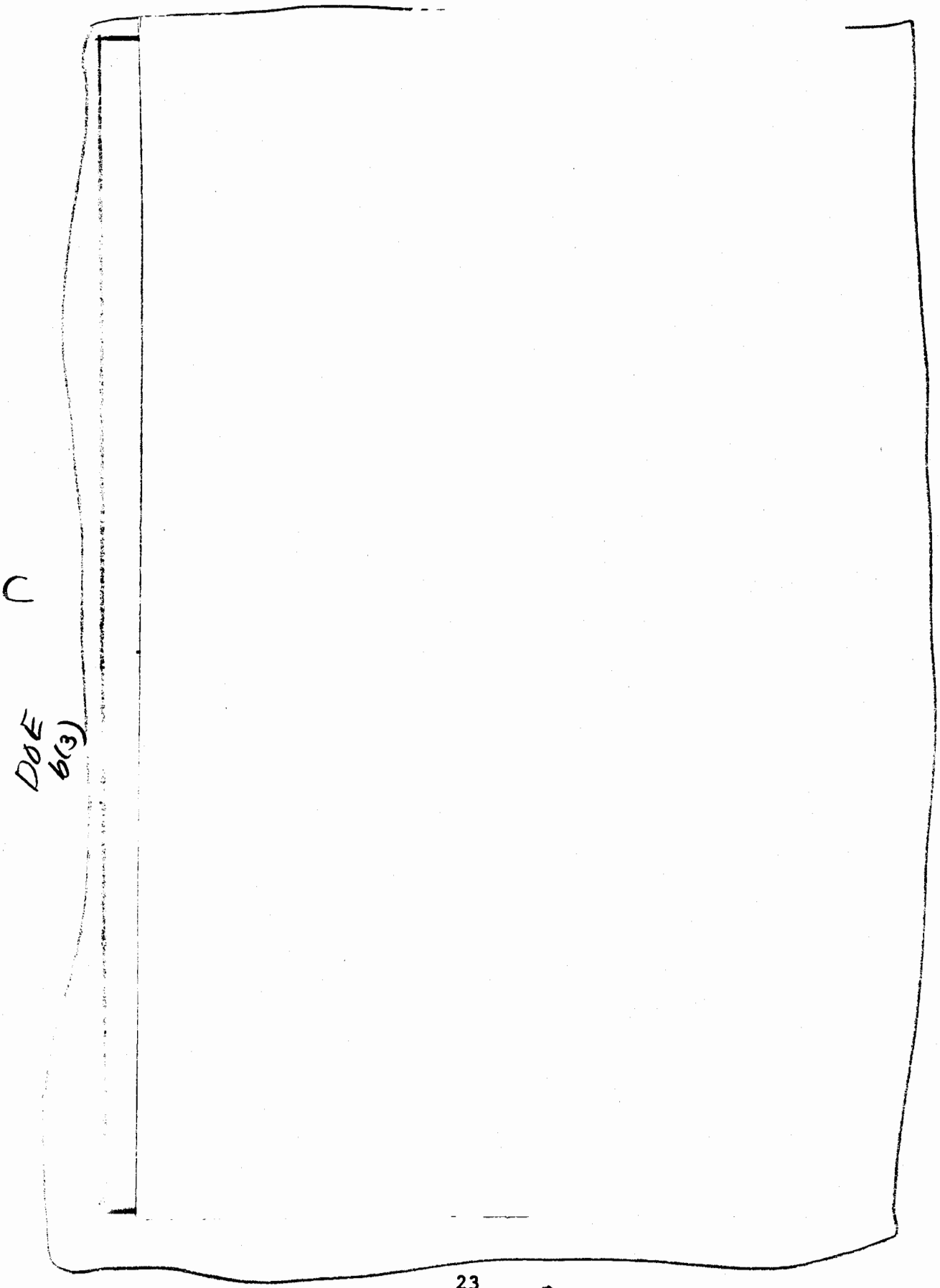


Figure 1 - B53-1 Bomb Exploded View



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screwdriver. The setting on the timer indicates the time from extracton of the pullout rods and detonation.

MC1199 Electrical System Safing Switch -- The MC1199 is manually operated external to the weapon and provides visual indication of safe or unsafe conditions during ground handling. It has three control positions: safe, retard, and free-fall.

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MC1204 Explosive Switch and Fuse Pack -- The MC1204 is a single package containing all of the explosive switches and electrical fuses used in the B53. It consists of four MC749 self-contained explosive switches, two SA1022 fuses, and four SA960 fuses.

MC1237 Interconnecting Box -- The MC1237 completes the circuits between the components in the main fuzing system. This interconnecting box contains no resistors but is similar in construction to the MC1203.

MC1262 Thermal Battery Packs -- Two MC1262 fast-rise thermal battery packs are used in the B53. The MC1262 is a two-section thermal battery containing a 12-volt fast-rise section and 28-volt power section. Basically, it is two batteries in a single case with a common negative terminal.

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MC1264 Thermal Batteries -- Two MC1264 thermal batteries are used in the B53 to provide dual channel power for the fuzing system. The MC1264 is nominally a 28-volt battery with an activated life in excess of 240 seconds. It is activated by electrical power from the 12-volt section of the MC1262 to either of the two MC1210 electrical matches in the MC1264. The SA925 thermal monitor is incorporated into the MC1264 to provide means to determine activation status of the battery.

MC1268 Interval Timer -- The MC1268 includes two MC1269 mercury-thallium switches and two SA906 motor-driven timers.

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MC4065 Power Pack -- The MC4065 contains a high voltage transverter, a trigger circuit, the neutron generator low voltage oscillator circuit and trigger attenuator, and an MC2969 Strong-Link Switch which are potted in a stainless steel housing.

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MC4066 Neutron Generator -- Two MC4066 generators are used to provide external initiation of the nuclear system.

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Parachute System – The parachute system includes three mild detonating fuze (MDF) systems, a 4-foot pilot chute, a 16.5-foot ribbon-type chute permanently reefed to 12 feet (retard chute), and three 48-foot ribbon-type chutes (laydown chutes), each reefed to 22.5 feet for 2 seconds after line stretch. Each parachute is packed into its deployment bag before assembly into a parachute stowage can.

The three MDF systems provide for parachute deployment, separation of the laydown extraction parachute, and release of the complete parachute system for high-altitude free-fall option (not available in B53-1).

The parachute stowage can is a honeycomb structure that provides a parachute volume of 26 cubic feet and contains two suspension line lug systems. One of the lug systems is used to attach the laydown chutes and to provide a load-carrying path to the rear case section. The other lug system is used to attach the retard chute. It contains a cutting anvil to be used, in conjunction with the MC1581 shaped charge mild detonating fuze system (flexible linear-shaped charge) in the rear case section, to cut the retard chute suspension lines in the laydown option. Thus, the retard chute deploys the laydown chute.

C. Nuclear Explosive Safety Theme

The safety theme of the B53-1 includes energy diversion through conductive metal barriers, protection of entry into the exclusion region by a strong-link switch that is enabled by a unique signal, and weak-link/strong-link collocation.

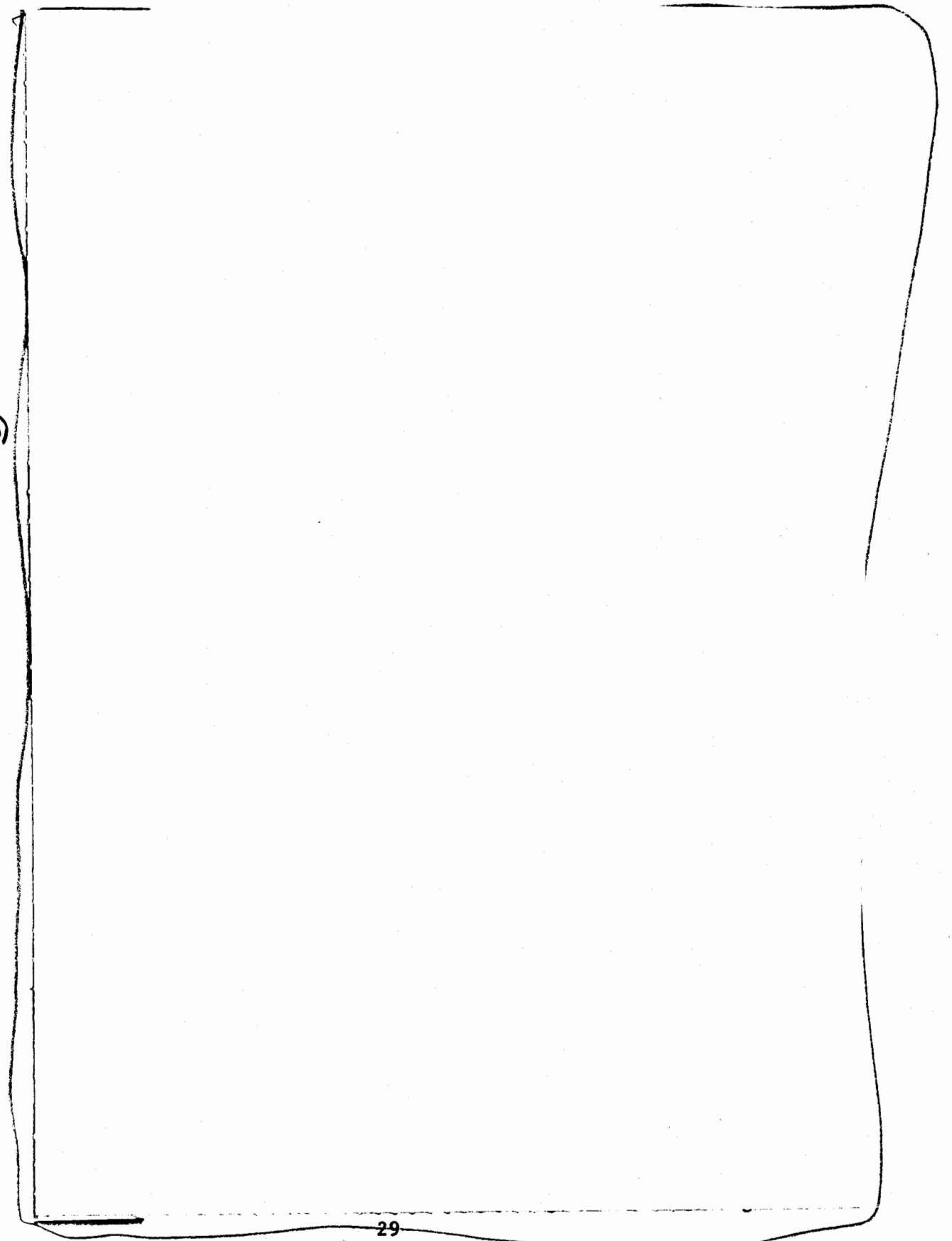
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- All remaining B53-1 pits in stockpile have been individually calculated to be inherently one-point safe.
- The design approach to provide isolation of critical circuits from sources of electrical energy in abnormal environments is to enclose those critical elements with an exclusion region. The entry of electrical energy into this region is through an MC2969 Strong-Link Switch that is enabled only by receipt of a unique signal. The unique signal is generated external to the bomb such that transmission of the unique signal indicates the intent to arm the B53-1.
- A Lightning Arrestor Connector is utilized at the bomb/pullout cable interface to provide protection against inputs to the bomb that could result from lightning strikes.

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TABLE 1 - Component Explosive Content and Firing Characteristics



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H. Shipping Configurations

Two shipping configurations exist during the activities addressed in this study. Both configurations utilize the H794 Hand Truck which is a caster-mounted metal truck used for shipping, storage, positioning and maneuvering of the B53 (see Figure 4). The H794 is approximately 10 feet long and 5 feet wide and weights approximately 1000 pounds. Pior to disassembly, the bomb is handled/transported and following disassembly, the basic assembly is handled/transported. When the bomb is being handled, the H795 Adapter Kit is used to adapt the B53 to the H794 (see Figure 5). The bomb is held in place by the two aluminum bands and longitudinal movement is resisted by a telescoping steel shear pin. When the BA53 is being handled, the H796 Adapter Kit is used to adapt the BA53 to the H794 (see Figure 6). The basic assembly is held in place by the two aluminum bands and longitudinal movement is resisted by a fixed steel shear pin. Figure 7 depicts the B53 installed in the H794/795.

I. Tie-down Specification

Figures 8 through 11 shows the over-the-road tiedowns and Figure 12 shows the on-site tiedowns. The on-site tiedowns for the B53 and BA53 are identical. The over-the-road configuration was successfully tested and the on-site configurations were evaluated and found satisfactory (Appendix A). These data are on file in Division 9613.

J. Permissive Action Link

S The B53-1 does not utilize a Permissive Action Link.

K. Command Disable

S The B53-1 does not have a Command Disable feature.

III. DESCRIPTION OF ELECTRICAL TEST EQUIPMENT

The only electrical test performed on the nuclear explosive is verification of the status of the MC2969 strong-link switch. A detailed analysis of the tester used is included in Appendix C.

PT4118 Multicircuit Continuity Tester

Description - A manually operated, multiple-purpose continuity test set used with the CB2297.

Tester Analysis Summary - Lab testing of the PT4118 has revealed output currents of 0.5 to 0.75 amperes through an external load of 5 ohms. This is in the form of 100 nanosecond wide pulses randomly generated during operation of the hand crank generator. This does violate the blue label limit of 0.1 ampere. The energy deposition by these 100 nanosecond.excursions is not sufficient to initiate the explosive devices within the B53-1.

Tester/Weapon Interface Analysis - No Critical Circuit Hazard exists because the energy deposition resulting from the 100 nanosecond high current excursions is below the no-fire level of all electro-explosive devices within the B53-1.

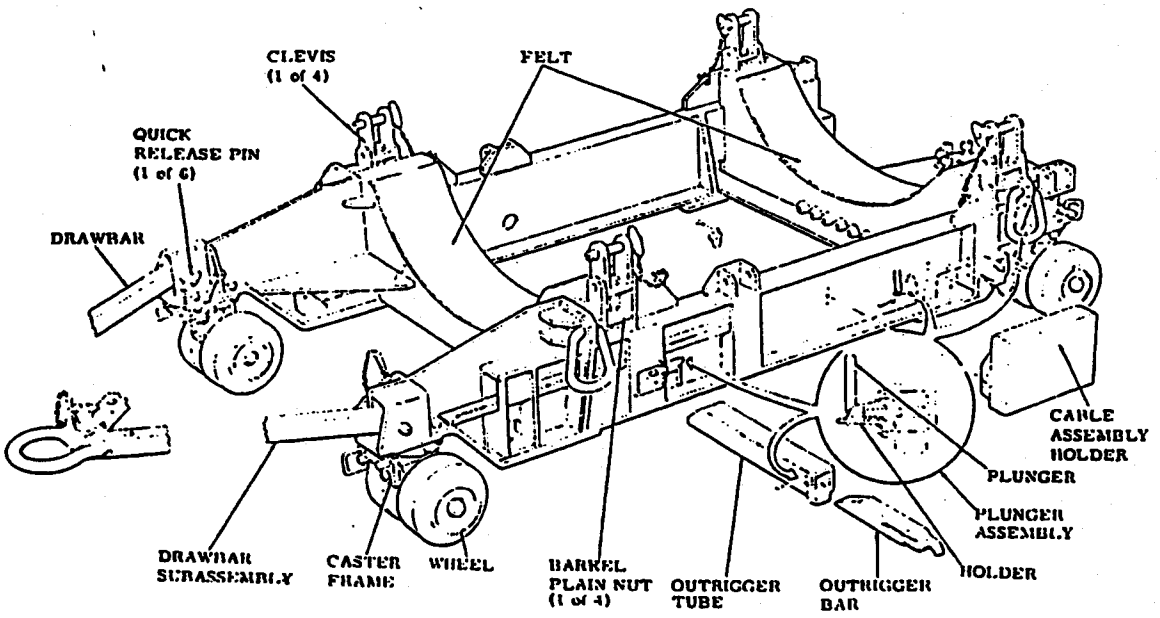


Figure 4 - H794 Hand Truck

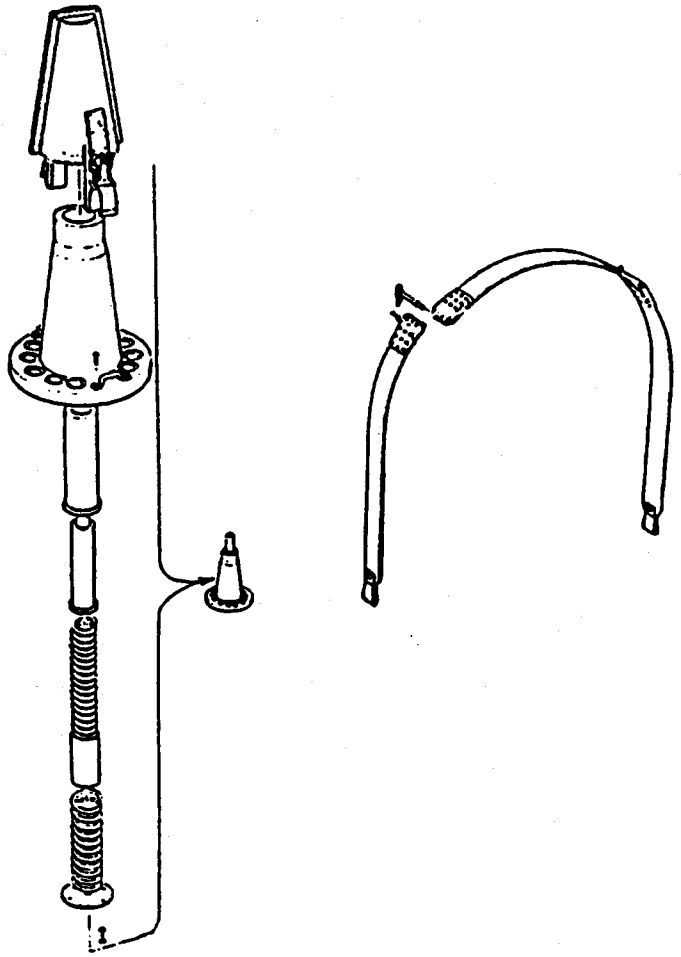


Figure 5 - H795 Adapter Kit

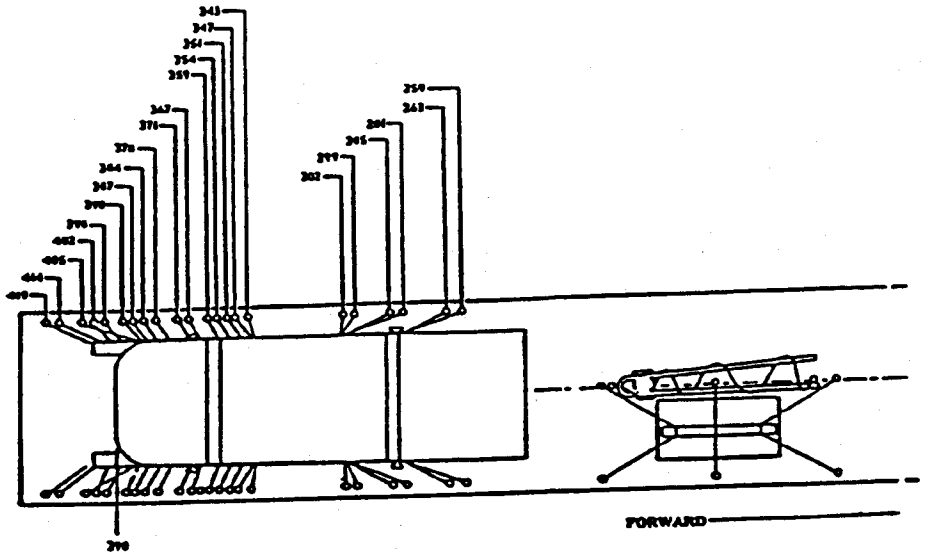


Figure 8 - H794 Tiedown Pattern

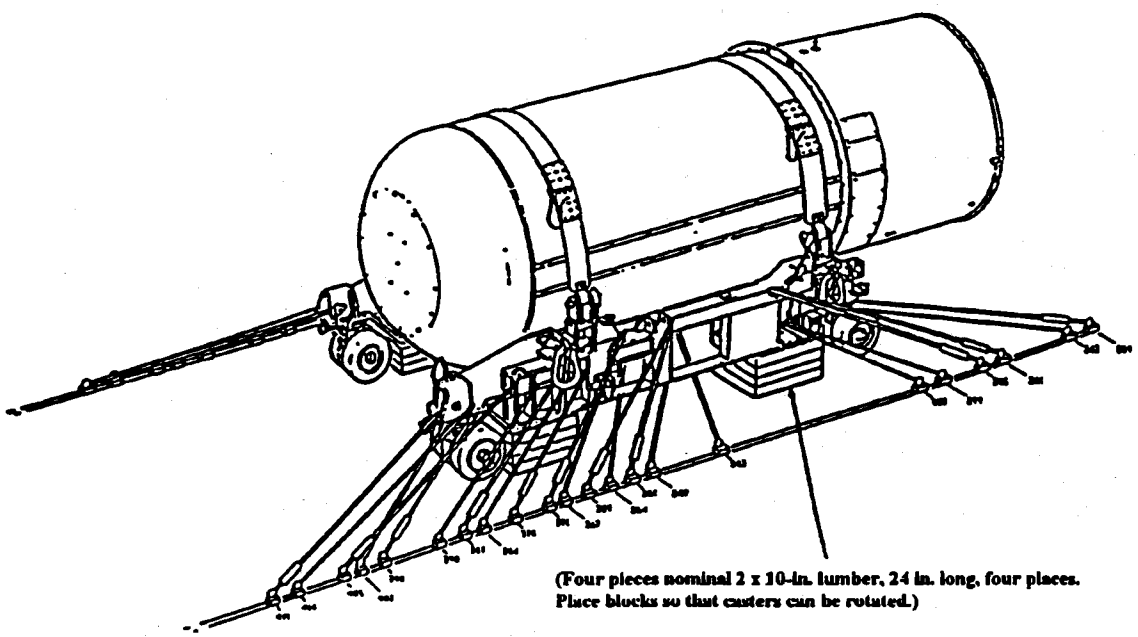


Figure 9 - Chain Routing and Blocking Arrangement

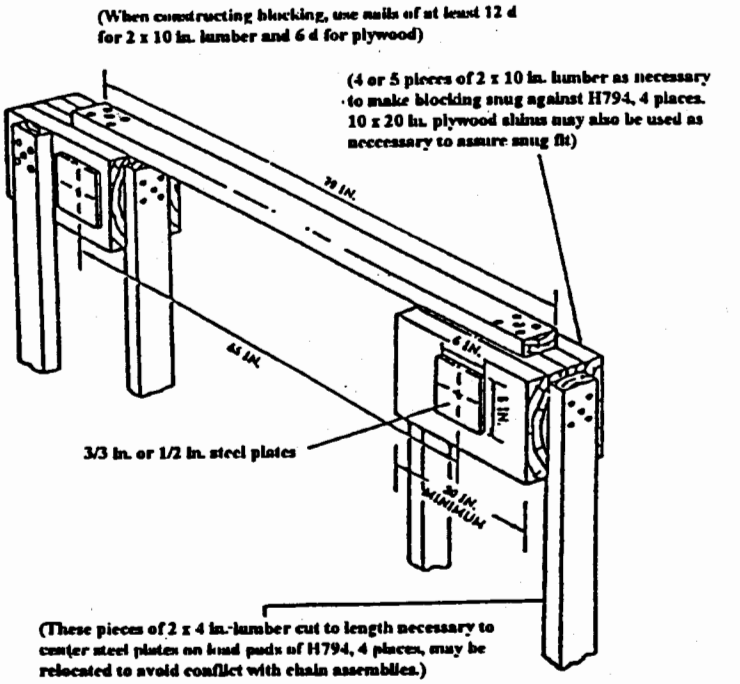


Figure 10 - Fabrication of Lateral Blocking

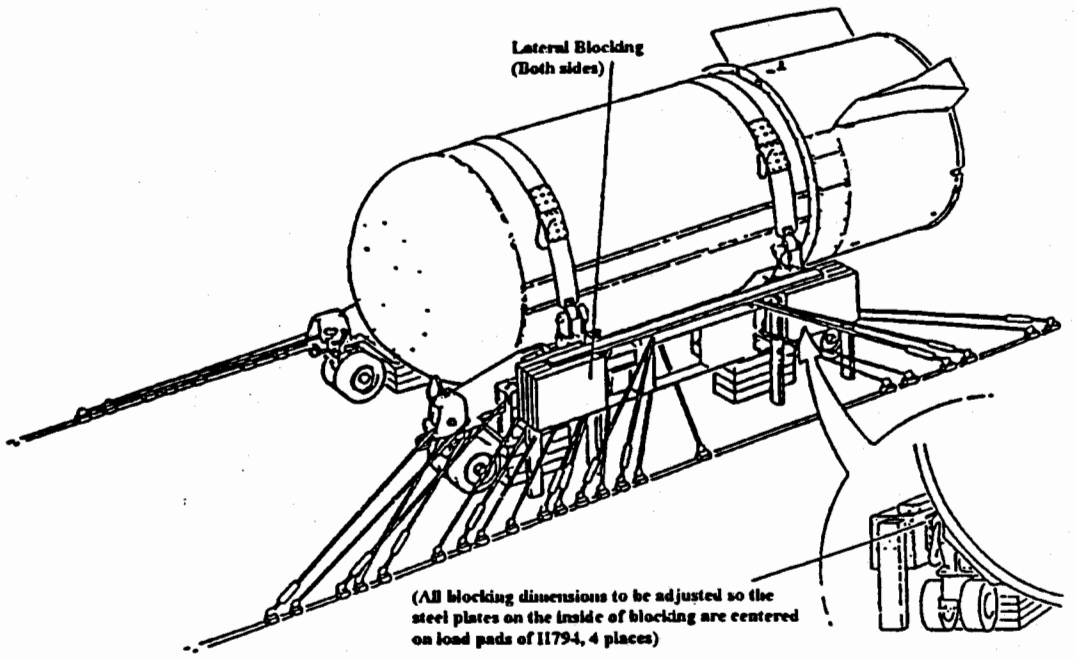


Figure 11 - Installation of Lateral Blocking

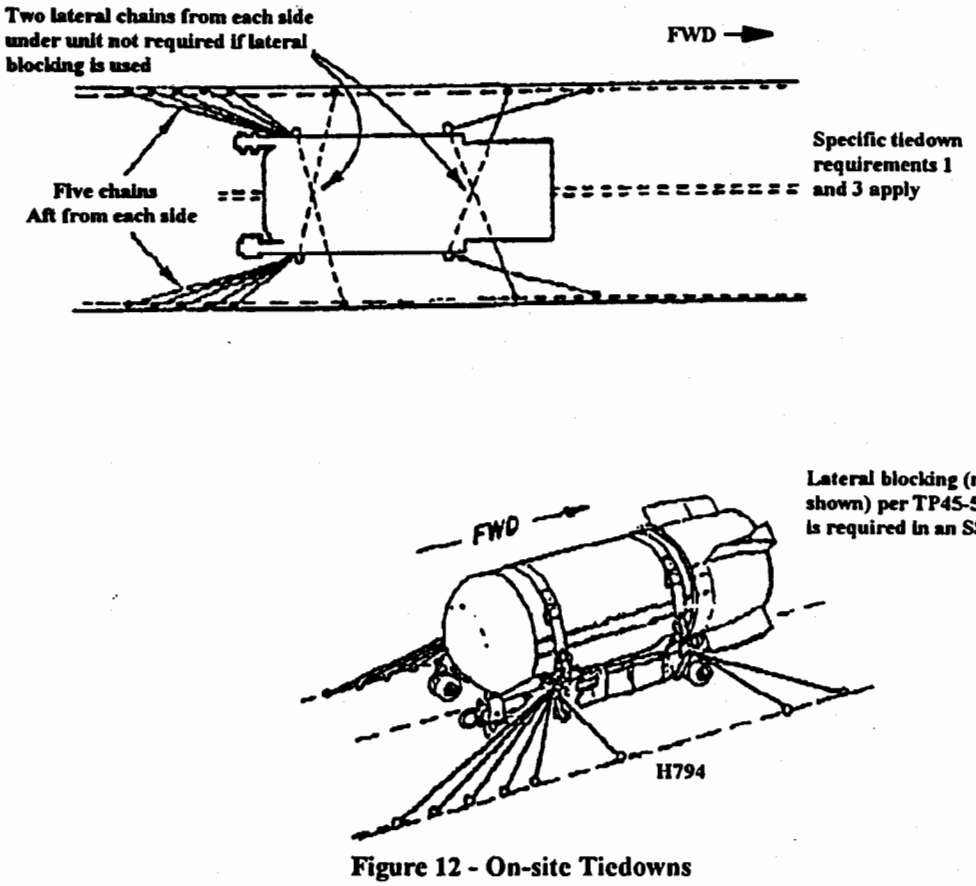


Figure 12 - On-site Tiedowns

IV. RESPONSE TO PANTEX PLANT ABNORMAL ENVIRONMENTS

A. Configurations/Facilities

Reference 2 was used to determine which abnormal environments are relevant to this B53-1 study. Through interpretation of the reference, Facility Categories II, IV, VI, VII, and VIII (12-104 Bays, Zone 12 Interconnecting Ramps and Passageways, Staging Igloos, Transport Operations, and Loading Operations) represent the possible facilities and sites that the B53-1 will encounter. The B53-1 will be Configuration C (Cased HE/Pit assembly but short of UU package configuration) and Configuration D (UU package configuration).

1. Single Abnormal Environments

The single abnormal environment responses are provided in Table 2. The table combines the five facility categories (not all environments are applicable in each facility), and considers two versions of Configuration C (the Aft Cap Assembly removed from the BA53 and the BA53 less fuzing and firing components).

Table 2 - B53 Single Abnormal Environment Response

Abnormal Environment	Configuration C	Configuration D	Rationale
Thermal			
Fire	P	P	HE will burn, confinement can lead to one-point detonation; one-point safe. If firing set present, strong-link/weak-link collocation provides assurance that firing set will not initiate detonators.
Cold	P	P	No unsafe condition postulated.
Heat	P	P	No unsafe condition postulated unless temperature reaches HE reaction temperature.
Electrical			
AC & DC	P	P	Cannot initiate exploding bridgewire detonators. If firing set present, strong-link interrupts all lines into exclusion region. Exclusion region protected by steel barrier.
EMR	P	P	Cannot initiate exploding bridgewire detonators. If firing set present, strong-link interrupts all lines into exclusion region. Exclusion region protected by steel barrier.
LIEMP	P	P	UU package protected by LAC. No testers used during disassembly.
Static Charge	P	P	Cannot initiate exploding bridgewire detonators. If firing set present, strong-link interrupts all lines into exclusion region. Exclusion region protected by steel barrier.
Chemical			
Water	P	P	Criticality becomes an issue during extreme accidents involving water flooding inside the pit. Prompt recovery (i.e., few days or less) from a water environment precludes any credible criticality concerns. If uranium is in contact with water for more than a few days them some corrosion will have begun. [redacted] (C, DOE b(3))
Processing Chemicals	P	P	No unsafe condition postulated.
Mechanical			
Impact	P	P	If firing set installed, strong-link continues to provide electrical isolation. HE is susceptible to one-point detonation. One-point safe.
Puncture	P	P	Objects penetrating basic assembly, causing actuation of the thermal batteries and bypassing the strong-link without the same or similar objects disabling critical elements is vanishingly small. HE is susceptible to one-point detonation. One-point safe.
Blast	P	P	HE is susceptible to one-point detonation. One-point safe.
Fragments	P	P	Objects penetrating basic assembly, causing actuation of the thermal batteries and bypassing the strong-link without the same or similar objects disabling critical elements is vanishingly small. HE is susceptible to one-point detonation. One-point safe.

Key: P - Predictable response.

2. Multiple Abnormal Environments

The B53-1 has no assured level of nuclear safety in a broad range of multiple abnormal environments as summarized in Table 3. The table combines the five facility categories and two versions of Configuration C as discussed for the single abnormal environments.

V. RISK ASSESSMENT REPORT

Not applicable for the B53-1.

VI. SPECIFIC SAFETY RULES

The following Specific Safety Rules currently exist for the B53-1 Bomb:

a. Upon bomb return and before disassembly operations are performed, the MC2969 strong-link switch shall be electrically monitored to verify the safe condition of the switch.

b. The thermal batteries shall not be electrically disconnected from the electrical component assembly interconnecting box in the critical assembly area.

c. In the NEA, the cover shall not be removed from the J7 connector on the MC4065 power pack.

Rules "b" and "c" should be deleted. Rule "b" does not contribute to the nuclear safety of the B53-1. In fact, removal of the thermal batteries enhances nuclear safety. It is our understanding that rule "b" exists only for the purpose of providing administrative control of power sources in the NEA. Positive control of the batteries would be accomplished by removing them from the NEA and taking them to the JTA assembly staging area. Rule "c" is unnecessary because analysis has shown that the weapon cannot be functioned by applying power to the MC4065J7 telemetry connector.

VII. IMMEDIATE ACTION PROCEDURES

The current immediate action procedures are those that are specified for most weapon programs:

(1) No attempt should be made to move the nuclear explosive.

(2) Turn off and disconnect all test equipment from the nuclear explosive.

(3) Further operations (including disassembly) on the nuclear explosive are specifically prohibited.

(4) Immediately notify the responsible M&H-SM assembly engineer.

These procedures appear adequate.

VIII. QUALITY TESTS

The only quality test performed during disassembly of the B53-1 for application in the Joint Flight Test Program is atmosphere analysis which includes checking for the presence of Tritium.

XIV. APPENDICES

A. -- Analysis of MC4065-J7 Telemetry Connector

B. -- B53-1 Transportation Tiedowns

C. -- Tester Analysis

APPENDIX A

Analysis of MC4065-J7 Telemetry Connector

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: August 2, 1993

to: J. S. Clabaugh, 5115

from: D. M. Pierce

subject: B53 Investigation of JTA Connector J7 Inputs

The MC4065 Power Pack for the B53 SIP has a JTA connector(J7) which is connected into the exclusion region. See enclosure 1. All pin connections have an isolation resistor except the ground return. The resistors are one (1) watt fixed wire wound construction. The failure mode, when over-power is to fuse open and stay open circuited. The following current/voltage/power would have to be applied to arm and fire the power pack X-unit or charge the output capacitor through the bleeder/divider network:

Function	Current-Amps	Voltage-Volts	Power-Watts
A1/B1	0.221	2,238	495
A2/B2-Peak	3.2	32,028	102,489
A2/B2-Steady State	0.225	2,318	502
A3/B3	0.032	330	10.5
TM Bleeder/ Divider	0.029	146,760	31.5

As can be seen from the above table, the one watt input resistors would burn open and the circuit would be unable to supply current for arming and firing functions.

If you have further questions please call me on extension 5-8317.

DMP:2571

Copy/Enclosures to:
2571 W. C. Curtis
2571 T. J. Williams
2571 D. M. Pierce

APPENDIX B

B53-1 Transportation Tiedowns

Sandia National Laboratories
Albuquerque, New Mexico 87185

date: August 17, 1993

to: J. S. Claybaugh, 5115

from: H. E. Morse, 9613

subject: B53 Nuclear Explosive Study

The B53 Tiedown Configuration specified in TP45-51D (SST over the road) was successfully tested.

The on-site tiedown was evaluated and found to be acceptable. The BA53 on-site tiedown is also acceptable.

HEM:9613:aw

Copy to:

9613	J. J. Roesch
9613	File, Tie-downs
9613	H. E. Morse

APPENDIX C

Tester Analysis

hand crank generator. The energy in these pulses is extremely small and is calculated to be 2.8 ergs. (An electro-explosive detonator normally requires tens of thousands of ergs to operate.)

WORST CASE FAILURE ANALYSIS

The PT4118 is housed in an aluminum enclosure which does provide complete mechanical protection. No internal failures due to crush could go unnoticed by the operator; (Use is not allowed if the enclosure has been crushed.)

Except for the LED assemblies and generator, all components are part of the printed wiring assembly (PWA) which encloses the output connector. The PWA is sandwiched between a phenolic insulator and an aluminum cover to prevent accidental bypass.

The failure of a single component will not result in a voltage greater than 36 volts or a current greater than 100 milliamperes through an external load. The following scenarios were analyzed:

(The presents of the high current pulses detected during lab testing are not part of the following analysis, but must be used when making a final determination of the tester's performance.)

COMPONENT	*FAILURE MODE*	*OUTPUT*	*NOTE*
CR1	OPEN	36 VOLTS	
CR2	OPEN	30 VOLTS	
R1	OPEN	0 VOLTS	1
R1	SHORTED	70 ma	2
R2	OPEN	0 VOLTS	1
R2	SHORTED	70 ma	2
DS1	OPEN	30 VOLTS	3
DS1	SHORTED	30 VOLTS	3
DS2	OPEN	30 VOLTS	3
DS2	SHORTED	30 VOLTS	3
D1	OPEN	0 VOLTS	1
D1	SHORTED	30V/.75V	4

Notes:

1. Open circuit, no output to external load.
2. Current level for dual circuit monitoring. 35 ma peak for single circuit.
3. LED will not function for that circuit. (A shorting plug is provided to ascertain LED performance prior and post test.)
4. With a counter clockwise turn on the generator, peak output is 30 volts. With a clockwise turn on the generator, peak output is 0.75 volts.

DG10001 COMPARISON

1. The PT4118 meets the appropriate requirements of DG10001 issue M for the following paragraphs:

   - 3.3 a; Is independent of the safety features within the NE and will operate safely for all normal and credible abnormal environments.

   - 3.3 b; The PT4118 design does meet the overall design requirements of the NE.

- 3.3 d; Will prevent catastrophic failure because of the incorporation safety features such as:. strong outer case, PWA protected from shorting
- 3.3 e; No high energy sources or AC power is used
- 3.3 f; The PT4118 is housed in a rugged aluminum enclosure providing sufficient protection against crush and the like.
- 3.3 g; No batteries are used.
- 3.3 h; Safe operation is independent of tester orientation.
- 3.4 a; An internal hand crank generator supplies power to the PT4118. Barriers are not provided around the generator because power is available only when a mechanical (rotating) force is applied by the operator. This would not be available to any extent during an abnormal environment such as a crush. Adding barriers would not raise the level of safety.
- 3.4 b; The location and insulation, and mounting of current limiters are clearly shown on the applicable drawing.
- 3.5 a; The complexity of the NET has been minimized
- 3.5 b; No capacitors or inductors, which could store energy, are used.
- 3.5 c; Dual current limiters are used but they are of the same type. The resistors used for current limiters are wire wound. The fail mode for this type of resistor is open which will result in an interruption of the flow of current to the load resulting in a safe condition.
- 3.5 d; The maximum current available during a single component failure will not exceed 100 ma with two circuits in use.
- 3.5 e; No positive feature is included on the tester to prevent current from flowing through interconnecting cables while they are being connected to or disconnected from the NE. Although, because the operator must provide a physical input to the hand crank generator, it would be physically impossible for the operator to do both, crank generator and operate a connector.
- 3.5 f; Interconnecting cable contains only wires to those circuits to be tested.
- 3.5 g; The connectors used on the tester and interconnecting cable provide positive mechanical locking features to prevent accidental disconnection.
- 3.5 h; Power is only available while the generator is receiving a mechanical input.
- 3.5 k; The circuits being evaluated in the NE are nonnative and therefore cannot provide an added voltage or current not provided by the tester.

2. The requirements in DG10001 issue M that PT4118 does not meet to the letter are met in other ways they are:

f. **Nuclear Explosive Tester Oversight Group (NETOG):** A Sandia group charged with the life cycle design stewardship of testers to be used with nuclear explosives.

g. **Tester Abnormal Environment:** An environment in which a tester experiences voltages, currents, energy, forces, etc., that are outside the range of acceptable, expected levels specified by the design or project group.

h. **Tester Catastrophic Failure:** A NET is said to undergo a catastrophic failure if a fault or faults occur for any reason that cause the tester's output(s) to exceed the normal output(s) as specified by the design or project group responsible for the NET. This may include (1) single faults that occur in one component and are non-propagating, or (2) multiple faults that occur in parallel due to a common cause, or (3) dependent failures due to propagation of a single fault.

2. DOCUMENTS.

a. **DOE Order 5610.11:** Program to Prevent Accidental of Unauthorized Nuclear Explosive Detonations

b. **EP401045:** Engineering Procedure, Definition of Computer Software Configuration Items

c. **EP401075:** Engineering Procedure, Electrical Testers For Use With Nuclear Explosives

d. **SAND85-2344:** Sandia Software Guidelines, Volume 1: Software Quality Planning

e. **SAND85-2345:** Sandia Software Guidelines, Volume 2: Documentation

f. **SAND85-2346:** Sandia Software Guidelines, Volume 3: Standards, Practices, and Conventions

g. **SAND85-2347:** Sandia Software Guidelines, Volume 4: Configuration Management

h. **SAND85-2348:** Sandia Software Guidelines, Volume 5: Tools, Techniques, and Methodologies

i. **SAND88-2955:** Guidelines for Software Security, (SFRD)

3. SAFETY DESIGN CRITERIA.

3.1 Safety Design Theme. A NET must not present a threat to nuclear explosive safety. A NET shall have a nuclear explosive safety design theme that is easily analyzed. Designers should use a "maximum-consequence" evaluation methodology, i.e., the worst case consequences of credible abnormal environments considering the energy sources, circuit design and the physical configuration of the tester.

3.2 Goal. Components, devices and circuits associated with safety features should fail in a safe manner.

3.3 General. Nuclear Explosive Testers should meet the following.

a. The design of the tester shall be independent of the safety features within a nuclear explosive and the tester shall operate safely for all normal and credible abnormal environments.

b. Design and evaluation of the tester must consider the overall design of the nuclear explosive under consideration. The existence and location of energy storage devices in the nuclear explosive shall receive careful consideration.

c. The lowest values of current and voltage that will adequately perform the function shall be used.

d. A NET shall incorporate safety features that will prevent catastrophic failure.

e. A NET requiring high energy power supplies, or a power source from any AC grid should be electrically and physically separated from the portion of the tester that connects to the nuclear explosive, see Figures 1 and 2.

f. Barriers or compartments may be used to simplify the analysis of the NET.

g. NETs with non-removable batteries requiring recharging shall have an interlock preventing the equipment from connecting to the nuclear explosive during battery charging.

h. Safe operation of the NET shall be independent of tester orientation. Tilting or rotation of a tester while in operation will have predictably-safe results.

3.4 Isolation. Nuclear Explosive Testers should meet the following.

a. Power sources should be located in a compartment(s) separate from other circuitry so that breakdown, improper use, or catastrophic failure will not deliver unintended power to the nuclear explosive.

k. Consideration should be given to voltages and currents reflected back to the tester from the nuclear explosive due to unexpected loads or internal generators. Under these conditions the tester must not apply excessive voltage and/or current to the nuclear explosive.

4. OTHER DESIGN CONSIDERATIONS.

4.1 National Electric Code. A NET must conform to applicable provisions of the National Electrical Code.

4.2 Electrostatic Discharge (ESD). For purposes of ESD protection, a connection on the tester should be provided for proper bonding.

4.3 Grounding. A NET should be designed so that no external earth ground connection is required.

5. NUCLEAR EXPLOSIVE TESTER SOFTWARE.

5.1 Development. Software development for NETs shall use proper software engineering techniques. These techniques are described in a five volume document "Sandia Software Guidelines" (SAND85-2344 thru SAND85-2348). The software shall be documented as required by Sandia EP401045 "Definition of Computer Software Configuration Items."

5.2 Safety Critical Software. Software designated as critical by the NESC review (EP401075), shall meet the following criteria.

a. Nuclear Explosive Safety Critical software should be developed in accordance with "Guidelines for Software Security," SAND88-2955 (classified SFRD).

b. The NESC software platform shall be reviewed by the NETOG and approved by the Nuclear Safety Department in accordance with EP401075.

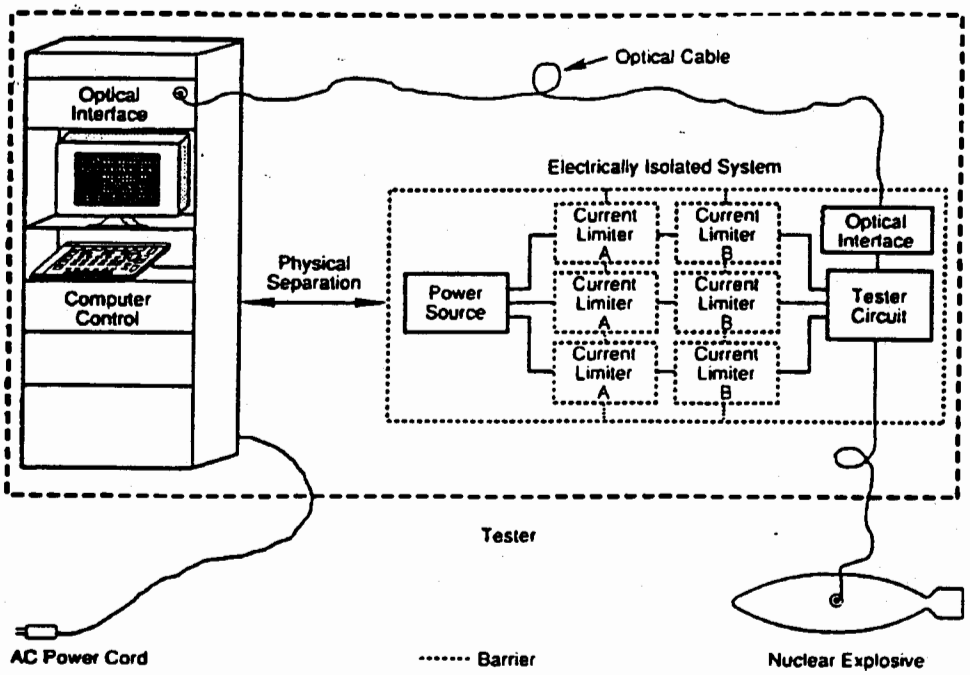


Figure 1. Possible configuration using optical isolation.

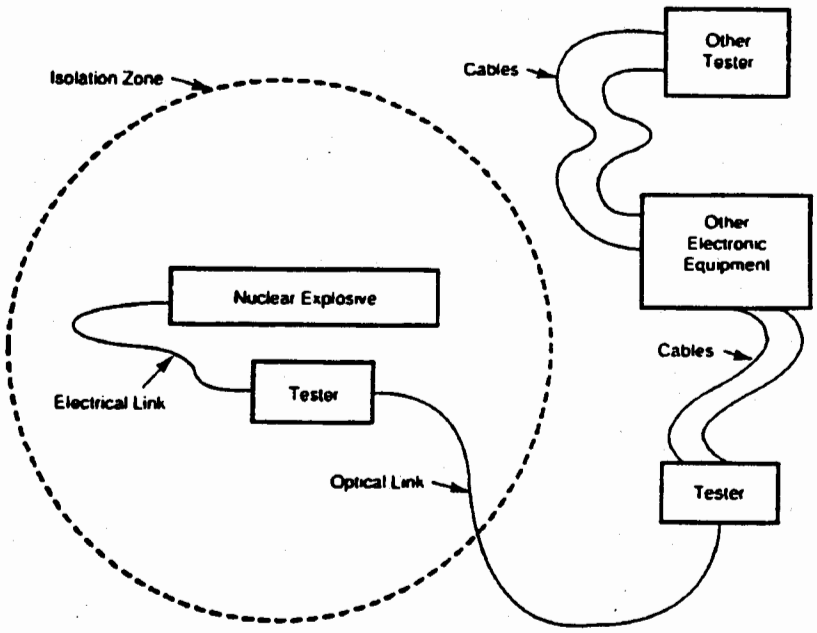


Figure 2. Isolate the tester and nuclear explosive from all electrical equipment and conductors except those that meet DG10001 standards.

SECRET

Sandia National Laboratories
Albuquerque, New Mexico 87185

date: October 4, 1993

to: F. W. Rider, DOE/AL/WSSB/NESD

J S Clabaugh

from: J. S. Clabaugh, 5115

subject: B53-1 Safety Study

Ref: SRD Document; dtd 8/25/94; subject: Input to the B53-1 Nuclear Explosive Safety Study at the Pantex Plant (U)

Two areas which were addressed at the subject safety study were not included in the referenced document.

1. Pantex personnel presented a proposal to stage the Aft Cap assembly in Zone 12 until nuclear system disassembly is approved rather than reassembling the Aft Cap assembly into a Basic Assembly and storing the Basic Assembly in Zone 4. The proposal included staging the Aft Cap assembly in building 12-64 which was not addressed under abnormal environments in the reference. Building 12-64 is in the same category as building 12-104 (Category II) and the abnormal responses provided in the reference are unchanged.

2. Additional information on over-the-road tiedowns was provided at the study. This information consisted of data from actual testing. Figures 1 and 2 show the test setup and figure 3 shows that the weapon yielded rather than the H-gear. Table 1 is the load cell data obtained until unit failure.

Copy to:
5115 J. O. Harrison

SECRET

WX-1-E-93-410S

August 27, 1993

Los Alamos
NATIONAL LABORATORY

Weapon Engineering
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LOS ALAMOS SOURCE DATA FOR B53 MOD 1

NUCLEAR EXPLOSIVE SAFETY STUDY (U)

BY:

E. D. Aragon, Jr.
B53 Project Leader
GROUP WX-1

Prepared for the DOE/AL B53 NESS to be held at
the Pantex Plant on September 28, 1993

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WX-1 File Cy: Vault - B53, I 18

RESTRICTED DATA
This document contains Restricted Data as defined in the Atomic Energy Act of 1954. Unauthorized disclosure subject to Administrative and Criminal Sanctions.

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DOE b(3)

I. APPLICATION AND GENERAL DESCRIPTION

The B53 was also fielded as a basic assembly (BA53Y1) for the B-58 pod application.

The bomb does not incorporate Insensitive High Explosive (IHE) or a Command Disablement system.[1]

The B53 physical characteristics are listed below:

Weight:	8890 lb
Length:	144.6 in.
Maximum Diameter:	50 in.

II. NUCLEAR SYSTEM DESCRIPTION

The "basic assembly" includes the nuclear system and the weapon electrical system (WES), designed by Sandia National Laboratories (SNL).

A cut-away of the B53 is shown in Figure 1. Hazardous materials contained in the physics package are listed in Table 1.

Fig. 1 - B53 Mod 1 Bomb

DOE h(3)

All WES and bomb components external to the nuclear system are the responsibility of SNL and will be covered in the SNL complimentary input document to this NESS.

DOE b(3)

The Alt was performed by DoD teams [illegible].

Nuclear System Basic Components and LANL Darwing Numbers

Basic Schematic	18Y-64117

DOE b(3)

Primary

High Explosive Assembly

DOE b(3)

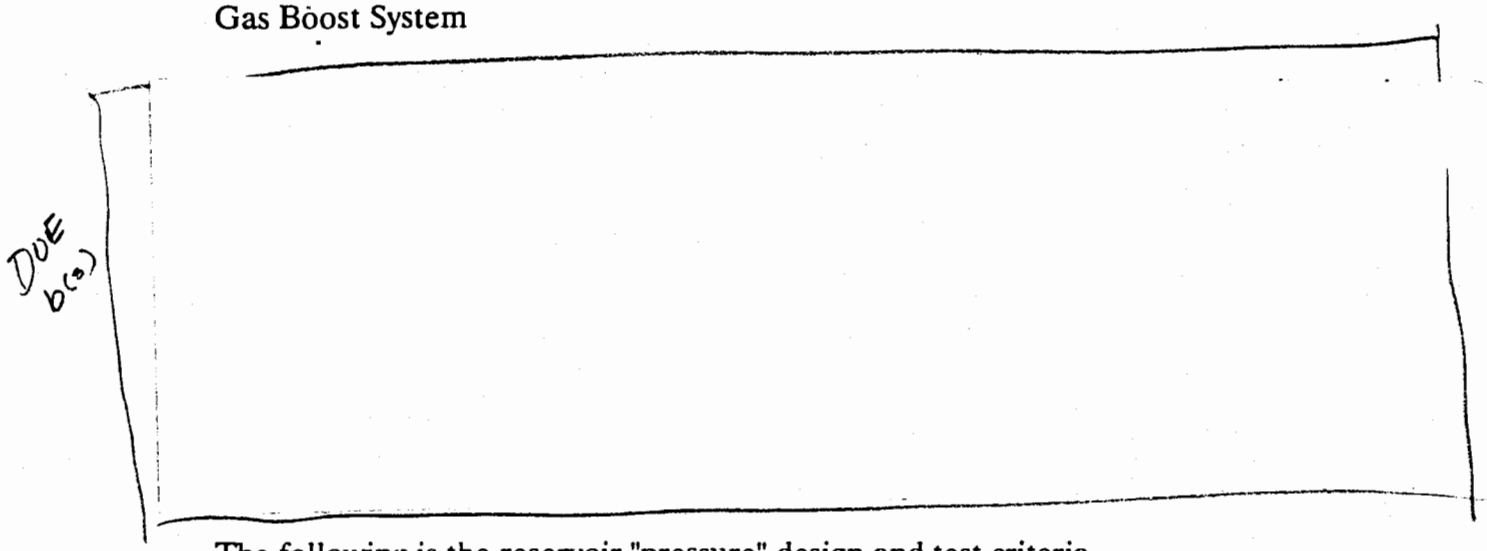
DOE b(3)

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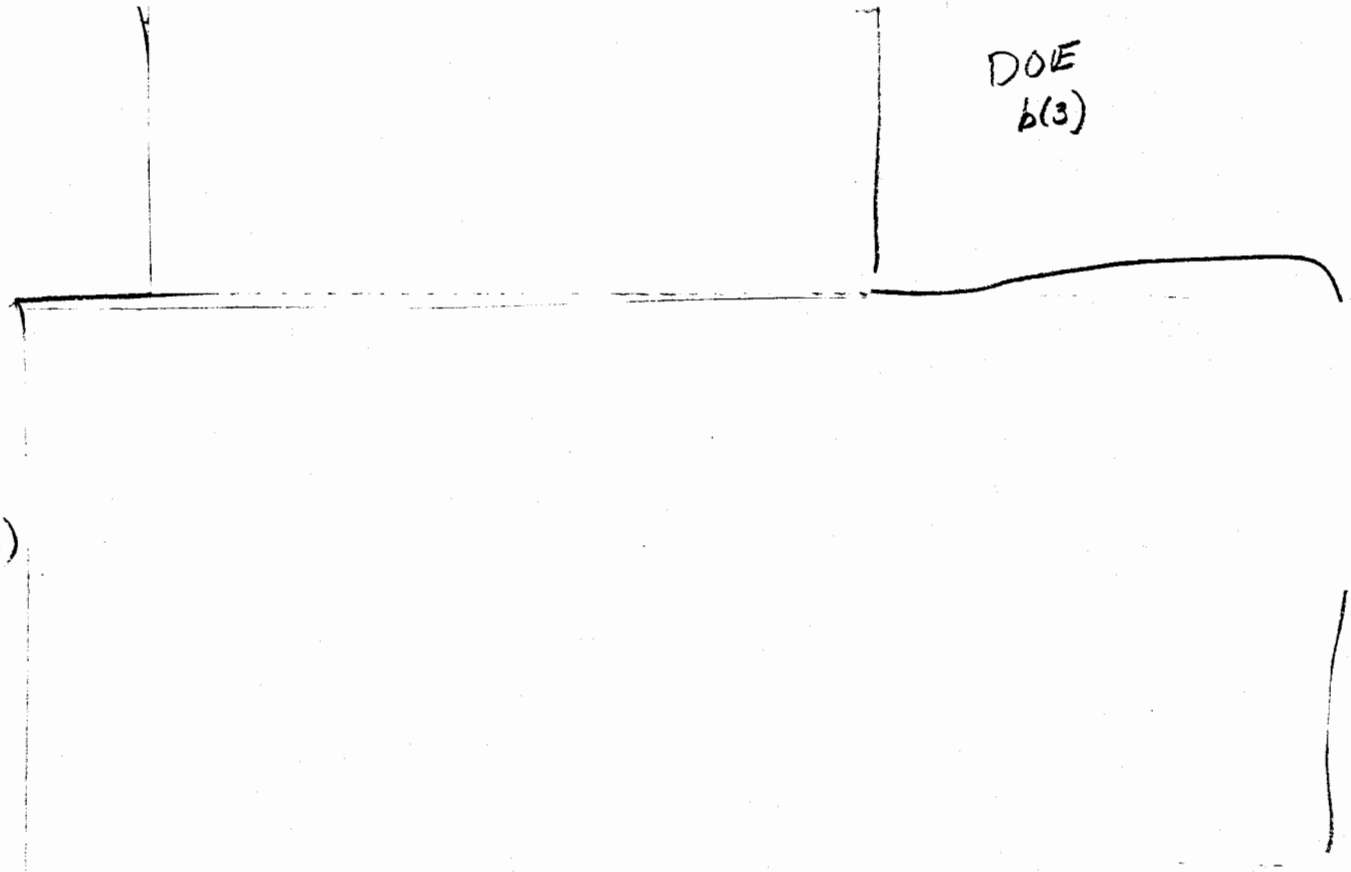
DOE (b3)

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Gas Boost System



The following is the reservoir "pressure" design and test criteria.



If a bomb is rejected and reservoir removal is desired, a procedure has been developed and approved by Los Alamos to crimp and cut the pit tube. A location on the pit tube allowing the use of two crimp tools is selected. The pit tube is crimped at two very close loactions, sealing both the pit and the reservoir from the atmosphere. The tube is cut

DOE
6(3)

between the crimps. The gas reservoir and its section of the pit tube, with the crimp tool still in place, can now be removed from the bomb.

One-Point Safety

All B53 nuclear systems remaining is stockpile are individually calculated to be inherently one-point safe.

DOE b(3)

DOE b(3)

Secondary

DOE b(3)

III. HIGH EXPLOSIVES SAFETY

Listed below in Table 2 are the high explosives used in the B53.

[redacted]

DOE 6(3)

PBX 9404 is a very energetic high explosive, and it is the standard by which most other HEs are compared. The figures and tables below provide a relative comparison of the sensitivity of the main HE charges in the B53 to other more modern high explosives used in later Los Alamos weapons.

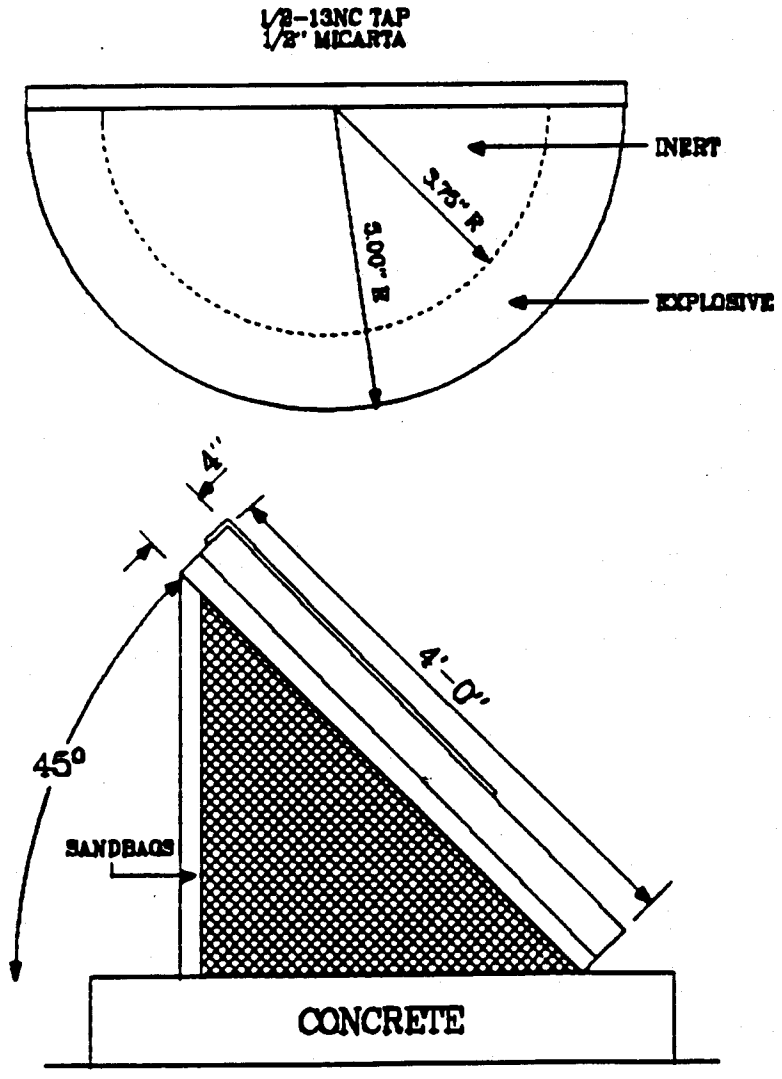
The Skid test, illustrated in Fig. 5 and data Table 3, relates primarily to handling safety during fabrication and assembly of bare main charge HE parts. In this test, a hemispherical billet of HE is dropped vertically onto a sanded steel target inclined at 45°. The height at which events are obtained 50% of the time (H_{50}) is reported. This test combines impact and friction such as one might find in a handling accident and generally gives a relative rating of in-process high explosives.

The large scale pin drop or Spigot test (Fig. 6) is used to assess the safety of large HE charges subjected to combined mechanical impact and shearing. The test assembly is shown in Fig. 7. As above, H_{50} is reported. The Spigot test data (Table 4) are normally applicable to full warhead assemblies subjected to impacts and deformation.

45° SKID TEST

10" DIAM. DROP VEHICLE

EXPLOSIVE 10 LBS
INERT 9 LBS



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Fig. 5 - Skid Test

THE SKID TEST IS USED TO EVALUATE HANDLING SAFETY OF BARE HE CHARGES

HE	50% DROP HEIGHT FT.	OVERPRESSURE PSI
COMP. B-3	10	1
CYCLOTOL	4	1
PBX-9404	4.5	15 to 20
PBX-9501	26	1 to 2
PBX-9502	>150	NO REACTION

Overpressure is measured with blast gauges 10 feet from the target.

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Table 3 - Skid Test Data Table

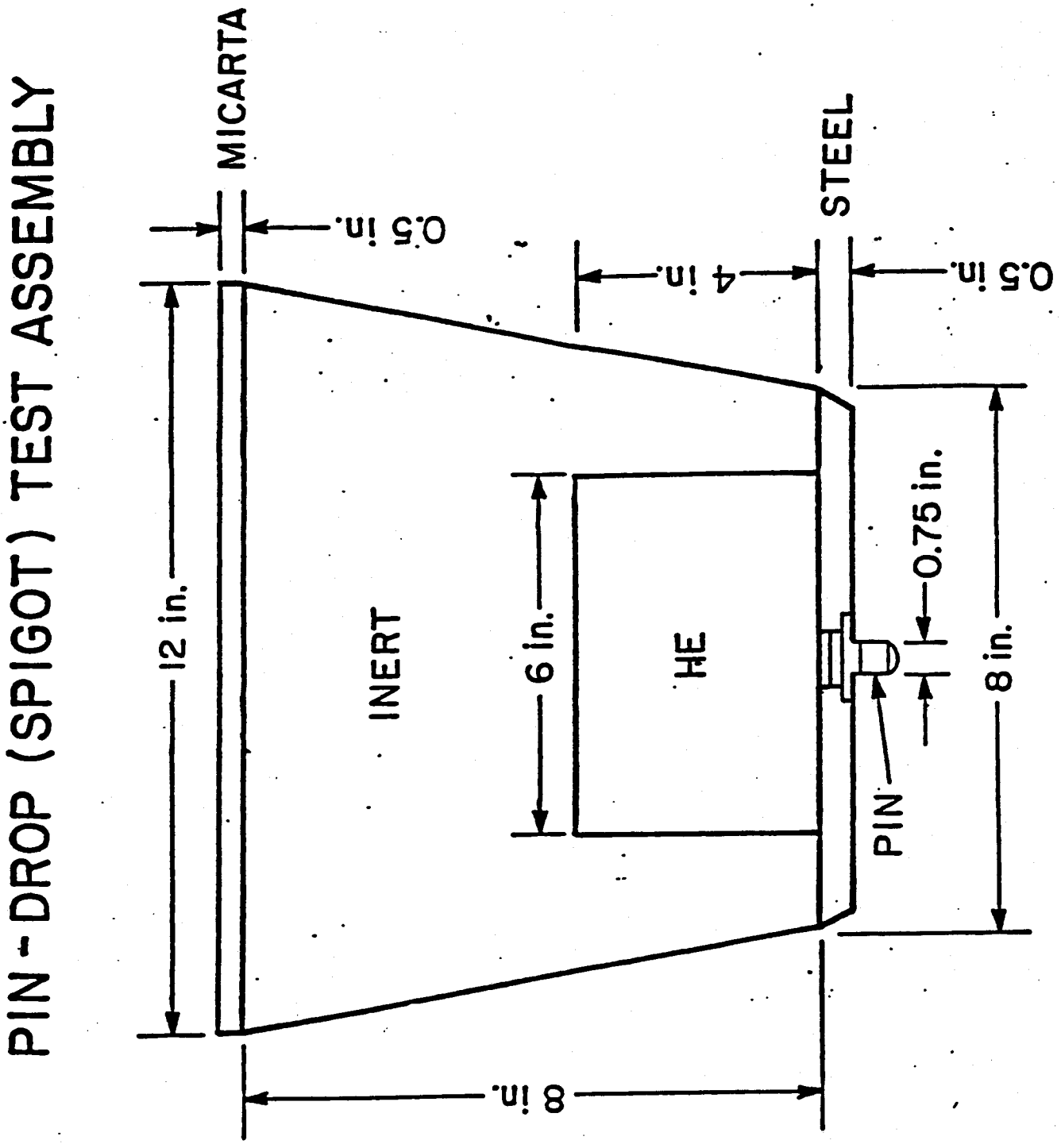


Fig. 6 - Pin Drop Spigot Test Assembly

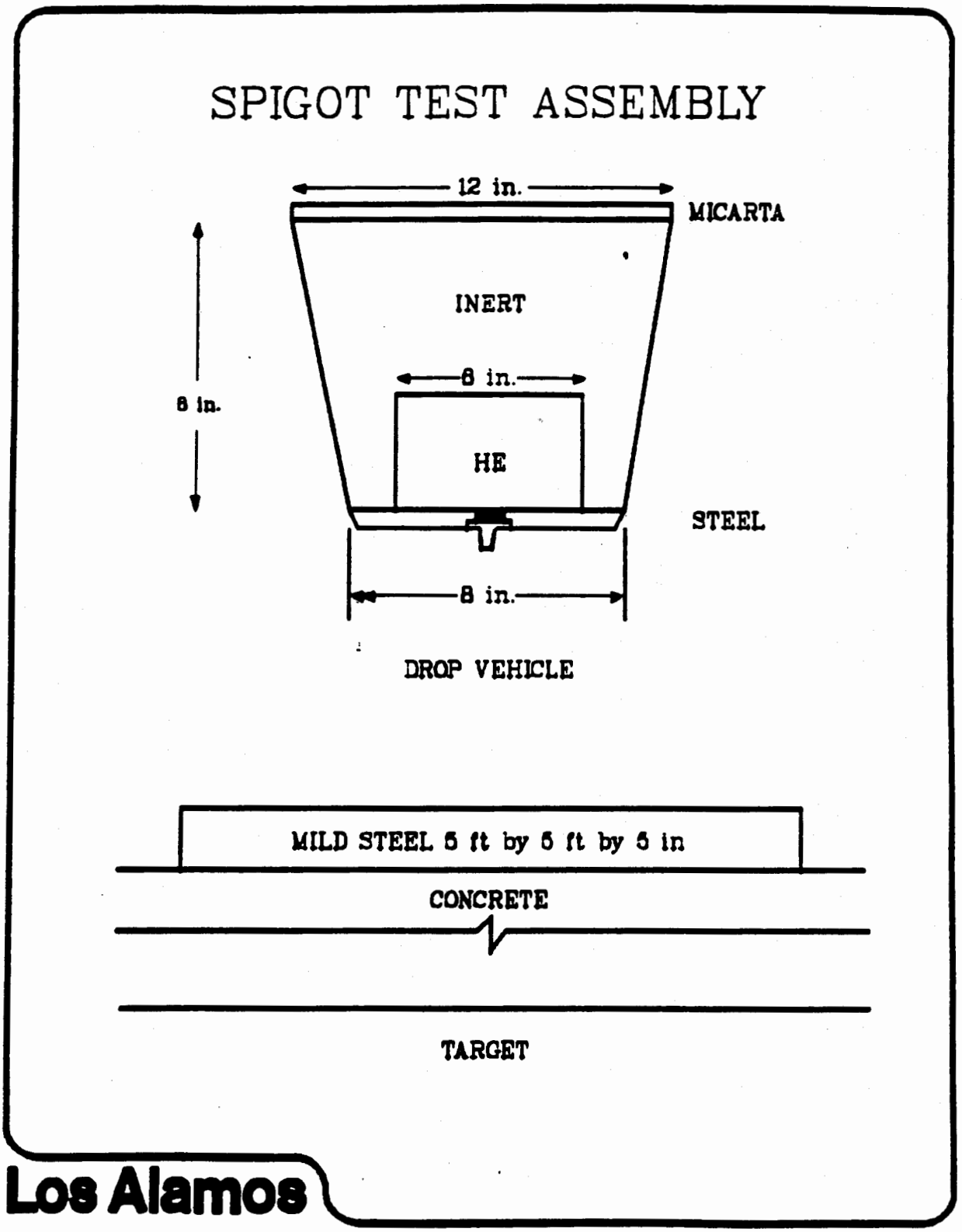


Fig. 7 - Spigot Test Assembly



THE SPIGOT TEST IS USED TO ASSESS THE RESPONSE OF THE HE WHEN SUBJECTED TO MECHANICAL IMPACT AND SHEARING

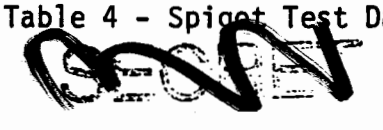
HE	50% DROP HEIGHT FT.	OVERPRESSURE PSI
COMP. B-3	85	1 - 2
CYCLOTOL	>150	NO REACTION
PBX-9404	49	20
PBX-9501	>150	1
LX-10	75	30
PBX-9502	>150	NO REACTION

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Table 4 - Spigot Test Data Table



The data show that the Cyclotol/Comp. B HE sensitivity levels fall in the mid to less sensitive portion of the tables presented. This is best shown by the Susan tests (Figs. 8 & 9). In these tests, Cyclotol and Comp. B are less sensitive than the HMX based PBX HEs. However, they are not as insensitive as PBX 9501 (IHE). The skid drop height of 10 and 4 ft respectively is surprising as compared to the spigot drop test height of 85 ft for Comp B and > 150 ft. for Cyclotol. The skid drop height is used for bare HE handling.

For thermal abnormal environments, several full scale weapon system tests contining Cyclotol as the main charge have been evaluated. These evaluations include both fuel fire tests and accidents. In all of these cases, the Cyclotol did not detonate. The following is a list of these fuel fire test and accidents.

Fuel Fire Tests

1.	W25 (6 tests)	No detonation, HE burned
2.	B28 (1 test)	No detonation, HE burned
3.	W53 (1 test)	No detonation, He burned

Accidents

1.	Bunkerhill (1964)	No detonation, HE burned
2.	McGuire (1960)	No detonation, HE burned

(D OE b(3))

Four accidents involving impacts have occurred that involved cast HE systems where Cyclotol was the main HE charge. Of these four events, one accident did involve HE detonation. The following lists these accidents.

Accidents Involving Impacts

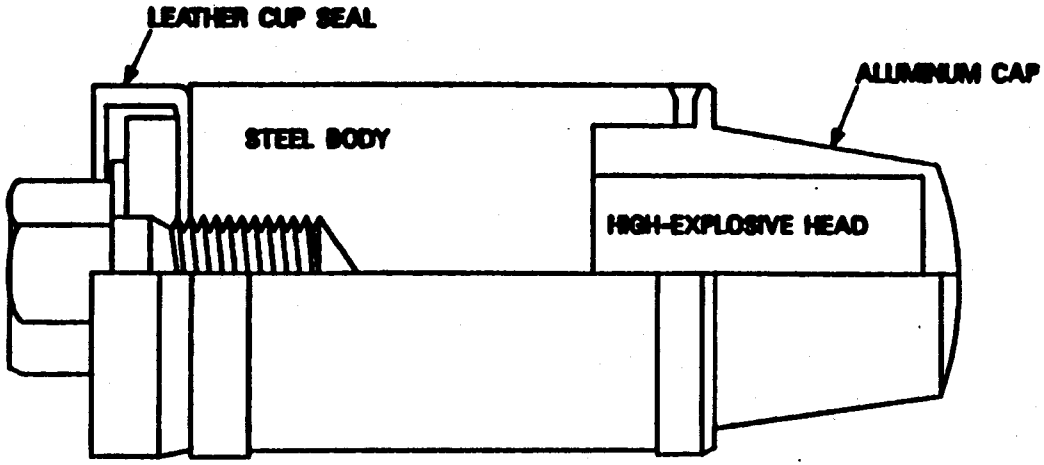
1.	Cumberland, MD. (1964)	No fire, No detonation
2.	Palomares, Spain (1966)	2 detonated on impact
3.	Thule, Greenland (1968)	No detonation, bombs destroyed by fire
4.	Damascus, Ark. (1980)	No detonation, unit recovered intact

DOE b(3)

HE Degradation

Selected properties of Cyclotol and Comp. B have been evaluated from aged stockpile materials and local testing. These evaluations have indicated that the material still performs as good as new. There are no signs of degradation from aging or incompatibility.

SUSAN TEST



HE SAMPLE	
DIAMETER	5.08 cm
LENGTH	10.16 cm
MASS	~0.45 kg

TARGET: ARMOR-PLATE STEEL
MEASUREMENTS: PROJECTILE VELOCITY
: AIRSHOCK AT PRESSURE GAUGE
OBJECTIVE: DETERMINE RELATIVE ENERGY
: RELEASE

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Fig. 8 - Susan Test

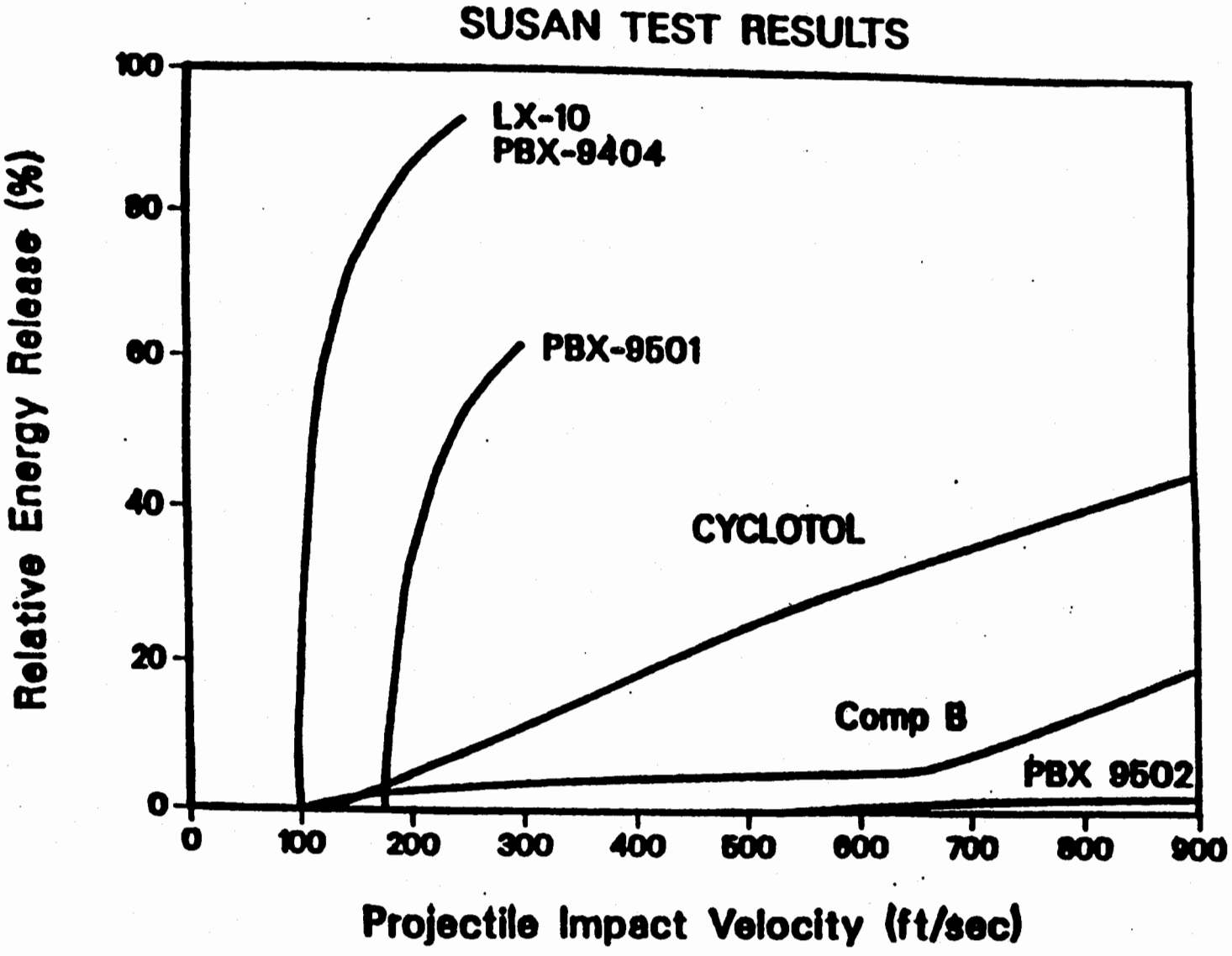


Fig. 9 - Susan Test Results

Material Compatibility

Long term full scale and short term small scale material compatibility tests are carried out for all weapon development programs. These tests involve accelerated aging studies of the warhead materials. In the small scale studies representative material samples are stacked in contact with each other as would occur in the warhead during the stockpile life and are subjected to temperature cycling designed to simulate the STS limits of the weapon and accelerate the aging process. Gas samples are collected and analyzed during the tests, and the small scale assemblies are disassembled and inspected after the test. The tests normally take 6 months, 1 year, or many years to complete, and are intended to represent a 20 year stockpile life. Full scale accelerated aging tests involve the complete weapon and often continue during the stockpile life of the weapon. Incompatibilities that are revealed during the weapon development are corrected by changing materials or design.

Another program carried on at Los Alamos is the explosive compatibility program. Explosives and formulations of explosives and all materials that come in direct contact with them or are employed in HE processing areas are tested. The materials may include floor wax, cleaning solvents, adhesives, mold releases, etc. The tests include vacuum stability tests and differential thermal analysis. Deviations from standard or expected behavior will cause materials to be rejected or forbidden from use with explosives or in explosive processing areas. Current materials found in HE assembly/disassembly areas have been approved for use with ALL explosives in general use today. Therfore, there are no incompatibilities with the materials and surroundings presently found at Pantex and the B53 high explosives.

Stockpile Evaluation

In general, the stockpile and quality evaluation program for the B53 follows that of most other Los Alamos systems. DOE b(3) Typically, bombs are randomly selected from the stockpile and returned to Pantex for disassembly and evaluation. To date, these unit evaluations have revealed nothing of consequence. Minimal HE cracking has been observed but deemed inconsequential. DOE b(3)

Additional stockpile information was obtained when the W53 was retired in 1987-88. These units revealed no problems with the nuclear components other than what is stated above.

The last full SLT was conducted in 1983. Since then, there has been minimal testing of this weapon system. One bomb was looked at in 1987 and another in 1990. A positive outcome from this NESS will allow the evaluation of another B53 bomb.

Detonators

[redacted]

Samples of all DOE detonators are tested during development by thermal cycling, temperature shock, vibration, and acceleration primarily for reliability assessment. These tests also relate to the safety aspects of the detonators. The 1E26 detonator assembly has successfully passed all the environmental tests. Additionally, these detonators have been routinely sample tested during preproduction, production, and stockpile sampling with no deficiencies in safety or operational aspects noted.

Valve Safety

The Type 1A valve is actuated by Type 1A squibs. A piston is driven down through the bore that severs the pit and the bottle tubes allowing boost gas to enter the pit. This valve poses no explosive safety concerns because all the reaction products and the pistion motion are contained within the valve body. The actuators are designed to function under a 28 volt source with a 500 ma all-fire and a 150 ma no-fire current rating.

Actuator ESD Sensitivity

These actuators are known to be sensitive to electrostatic discharge (ESD) when tested with a standard ESD pulse (20kV, 500 pF through 500 ohms) pin-to-case. Tests of the Type 1A squibs have resulted in failure to pass ESD pin-to-case tests with conditions of 5 kV, 500 pF through 500 ohms. Therefore, special bonding practices during all assembly/disassembly operations are required, and shorting plugs should be in place at all times after the firing cables are disconnected.

DOE
b(3)

Fig. 10 - 1E26 Detonator

IV. CRITICALITY SAFETY

Single Units

[redacted] From a criticality perspective, this all-uranium pit has three characteristics which distinguish it from Pu pits found in the stockpile. However, all pits of Los Alamos origin, whether they contain uranium, Pu, or both as the fissile material, only pose a criticality hazard (as single units) during extreme accidents involving water flooding inside the pit.

Type 76 Pit

The three distinguishing characteristics are:

* Uranium is corroded much more slowly by water than is Pu, either alpha or delta.
* Uranium is attacked much more slowly by H_2 gas than is Pu, either alpha or delta.
* [redacted]

The implication of these first two points is that prompt recovery (i.e. few days or less) of a B53 from a water environment precludes any credible criticality concerns. That is, insufficient uranium corrosion and hydriding will have occurred to give rise to the hazards discussed (for Pu) in the TP 60-1 manual, particularly section 3-2.5, flooding/criticality. Obviously, if water has not entered the pit then there are no criticality concerns even for prolonged underwater conditions. However, if a unit is involved in an accident leading to even possible internal flooding, then it would seem prudent to assume such.

The two extremes from a criticality standpoint are full water reflection outside [redacted] and essentially zero reflection outside. For these cases, minimum conditions are:

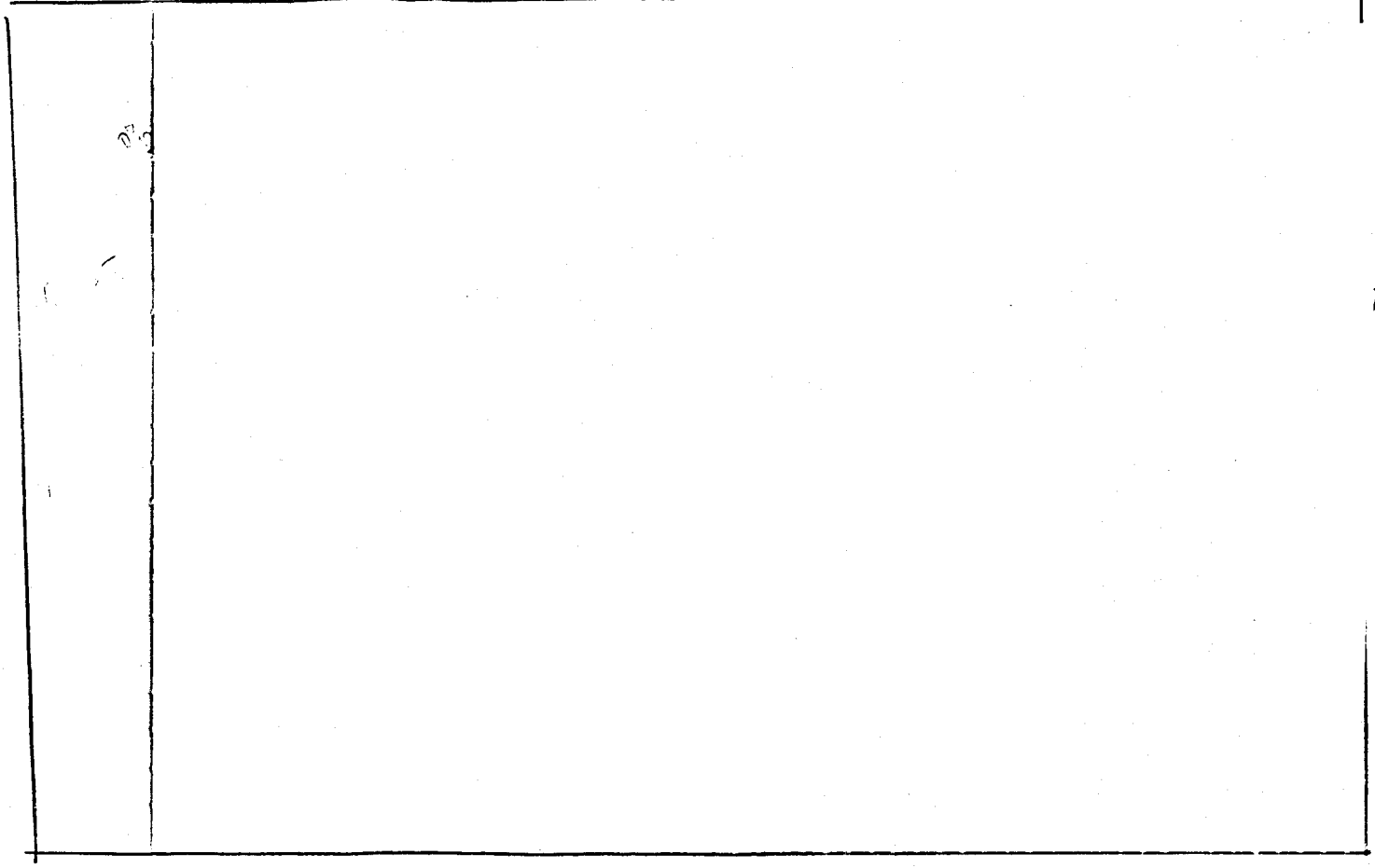
Reflected

[redacted]

Bare

[redacted]

Figure 11 (Figure 11 from Doc. LA-10860-MS) presents critical volume and indirectly, critical mass information which supports these statements



DOE b(3)

Arrays/Multiple Units

DOE b(3)

For a modest number of units (approx. 10), there are no criticality concerns for any spacing/arrangement. This remains true in a water flooded and/or reflected environment.

DOE b(3)

DOE b(3)

The largest, most reactive array achievable is approximately a 2x2x3, based on current stockpile data. For pits in DT-22 containers (the currently approved shipping array), the SAR shows that an infinitely large array would still be subcritical.

Should flooding of a storage area containing multiple units occur and if water ingress to the inside of the pit is considered credible, then the precautions listed under SINGLE UNITS in reference 4 should be observed.[4] 87

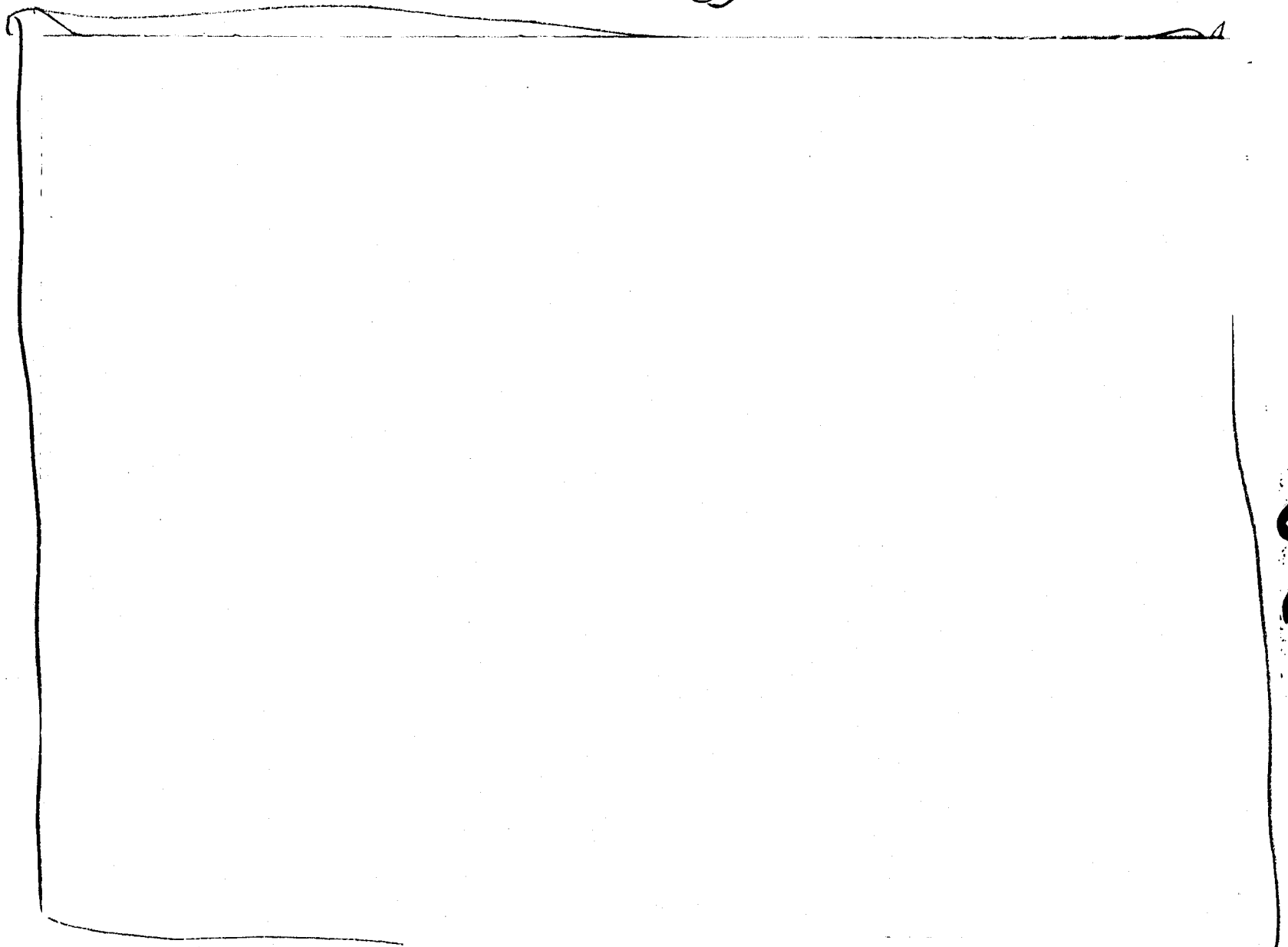


Fig. 19. Critical mass vs ^{235}U enrichment of uranium metal. The dashed line represents the enrichment below which a piece of uranium metal cannot become critical, as determined by an international reactor physics program.

Fig. 12 - Critical Mass vs ^{235}U

V. NUCLEAR EXPLOSIVE SAFETY ORDERS AND SUPPLEMENTAL DIRECTIVE

Los Alamos believes that we are in compliance with the applicable provisions of DOE 5610.11, and AL 5610.11

INTRODUCTION

Following is the Mason & Hanger/Battelle Pantex input document for the Nuclear Explosive Safety 5 year B53-1 Mechanical study. This document presents the Process Flow for Disassembly, Tooling used in handling the Nuclear device, and a listing of all approved O & I Standards.

B53-1 UNIT FLOW

Attachment A defines the typical flow of the unit from receipt at Pantex (by Safe-Secure Trailer SST), through the complete disassembly and inspection process to obtain Parent Unit Parts for support of a B53-1 JTA.

The unit is obtained from the DOD by the DOE and transported to Pantex via SST. At the time of receipt in Zone 4 a receiving inspection for Safeguard Verification (Ref General Standard 7-0849.3), Serial Number and special markings conformation, and potential damage, etc. is performed.

When the unit is scheduled for operations, it is transported to Zone 12-26 loading dock by Pantex transportation personnel. The unit is delivered to 12-104 Bay 8 where it is removed from the H794 Hand Truck.

Disassembly is completed per NEOP N53-301800.

The End Cap Assembly is then staged in Zone 12 and the Basic Assembly is transported back to Zone 4 staging area.

B53-1 NEOP AND O & I STANDARDS

Attachment C lists the B53-1 procedures which will be reviewed during the study. The date and issue may be different due to on-going work at this time.

The O & I Standards are all current at this time. The NEOP (N53-301800) will be reviewed prior to the Nuclear Explosive Safety Study according to the current policies which includes, but is not limited to the Evaluation Engineer, Operation Manager, Technical Writer and the Nuclear Explosive Safety Representative. This indicates that the NEOP will have been reviewed by all ES&H Departments, Production Supervision and an Independent Evaluation Engineer.

All disciplines will have reviewed and approved this procedure.

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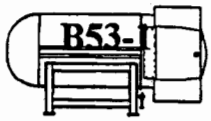
NEOP N53-301800 has been through Validation Review with recommendations from the Validation Review Team currently being incorporated.

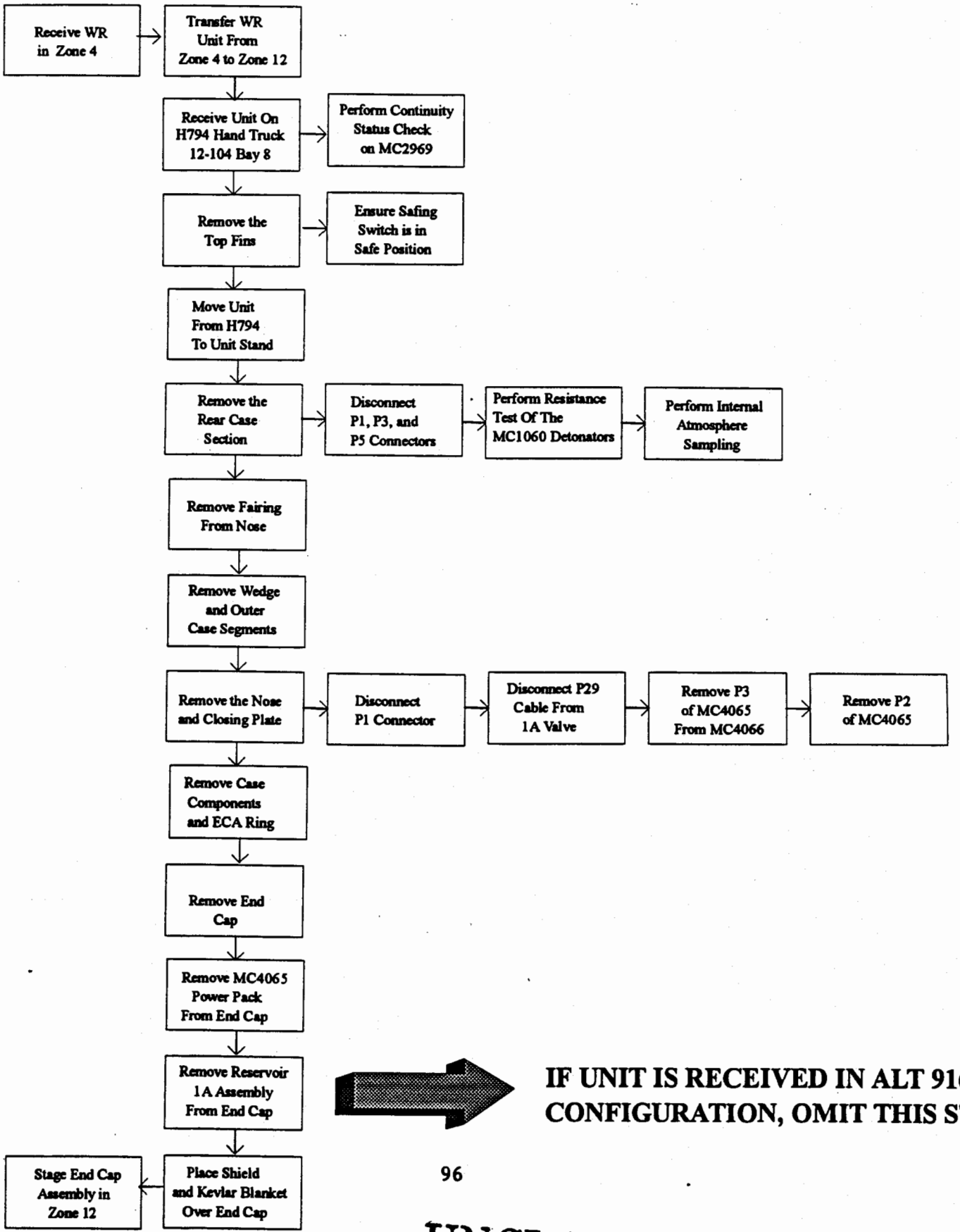
B53-1 LIFTING/HANDLING FIXTURES

This document also contains a list of the B53 Lifting and Handling Fixtures which are utilized in this Disassembly Process. All load testing of the Special Tooling in question is to be completed as stated in the attachment. All load testing will utilize testing procedures which have been approved by Nuclear Explosive Safety Master Study.

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B53-1 PARENT UNIT PARTS DISASSEMBLY





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B53 LIFTING/HANDLING FIXTURES

DRAWING	TITLE	SDS	ANALYSIS ON FILE	LOAD TEST	LOAD TEST ADAPTER	COMMENTS
053-2-009	Process Stand	None	Yes	No	None	
053-2-041	Beam Type Sling	12406	No (Doc. on file)	Yes 12,000#	053-2-242 053-2-243 053-2-248	Complete dwg. def. does not exist at Pantex. Certification is per IOP E-4202
053-2-054	Horiz. Insertion Fxtr	12446	Yes	Yes 2,400#	053-2-247	
053-2-055	Stand	None	Yes	No	None	
053-2-075	Unit Sling	12447	No (Doc. on file)	Yes 20,000#	053-2-249	Complete dwg. def. does not exist at Pantex. Certification is per IOP E-4202
053-2-078	Hoist Adapter	12406	Yes	Yes 7,650#	053-2-248	
053-2-174	Hoist Adapter	12458	No-(Doc. on file)	Yes 3,000#	None required	Complete dwg. def. does not exist at Pantex. Certification is per IOP E-4202

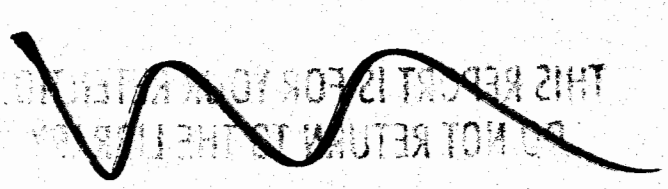
N:cwelch\B53

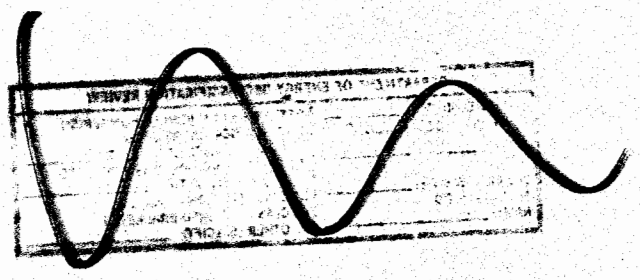
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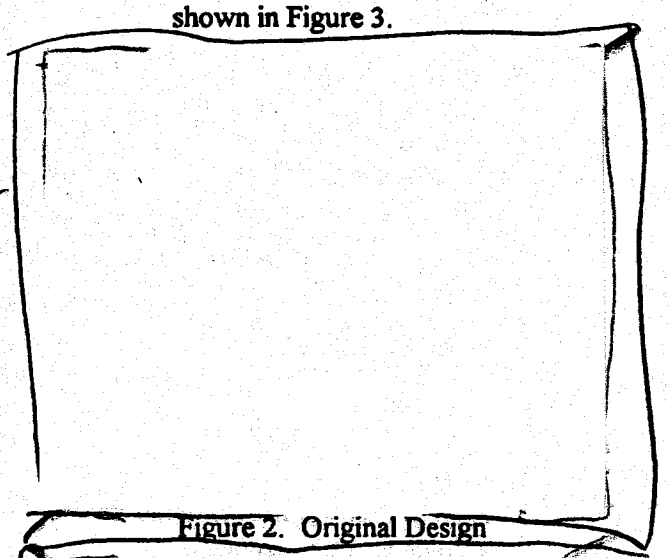
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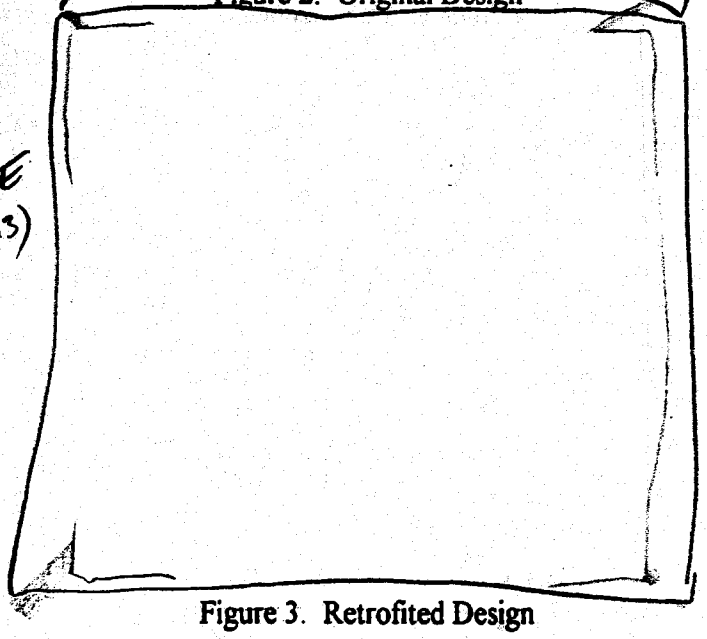
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The original design is shown in Figure 2 and the modified design is shown in Figure 3.



DOE b(3)

Figure 2. Original Design



DOE b(3)

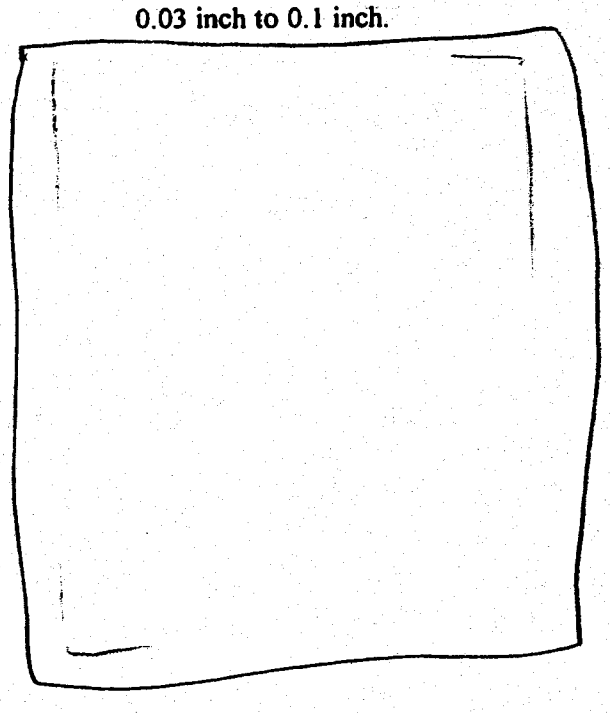
Figure 3. Retrofited Design

There are abnormal environments that will eventually defeat their isolation features. In the B53-1, the strong-link switch is located in relation to existing B53Y1-0 elements that have functions critical to system operation such that these vital elements become irreversibly inoperative before the isolation features of the strong-link switch are bypassed. The weak-links in the B53-1 system are the X-Unit capacitors and the nuclear system high explosive.

The power pack, which contains the strong-link switch is surrounded by the X-Unit capacitor bank. The power pack and the B53-1 system are divided into two zones:

A. Zone 1 contains the input circuits for the MC2969 and most of the B53Y1-0 carryover components.

B. Zone 2 is isolated from Zone 1 and external electrical sources by the MC2969 and the barriers. Zone 2 contains the power converter, the X-Unit capacitors, the trigger circuit, the detonator cables and the primary. The barriers between Zone 1 and Zone 2 are all steel material and varing from 0.03 inch to 0.1 inch.



DOE b(3)

- Lightning protection is provided against inputs to the bomb that could result from lightning strikes by a Lightning Arrestor Connector (LAC) at the bomb/pull-out cable interface. All signals entering the bomb case are routed through the LAC and the shell of the LAC is electrically connected to the bomb outer case. The LAC is designed to

g el fg toT ldg 'calgb ealgd pfr hr

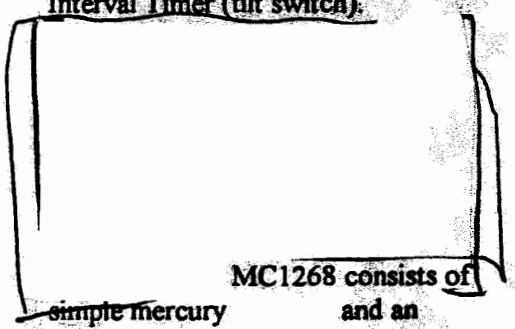
g T o d gn h gArresgArres l ng

explosive except when directed by competent authority."

The B53-1 does not include a PAL, but the design includes the following:

- The Aircraft Monitor and Control (AMAC) system includes a Bomber Coded Switch (BCS), similar to a PAL.

Arming cannot be completed until the Trajectory Sensing System has actuated. Trajectory arming is accomplished by the MC1268 Interval Timer (tilt switch).



MC1268 consists of simple mercury and an electrical therefore, its major contribution ground handling safety.

"There shall prevent

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Option #	Option Description	Relative Safety Improvement				Relative Increase In Time, Dollars, or People	Nuclear Detonation Safety And Scatter Effectiveness Ranking (1 = Best)		Weapon Security Improvement	New Equipment or Procedures	Ranking And Whether To Do or Not Do (1 = Best)		Comments
		During Transportation		During Storage									
		Nuclear Yield	Pu Scatter	Nuclear Yield	Pu Scatter		Trans.	Storage			Ranking	Do or Don't	
1	Remove D-T Gas Reservoir	None	N/A	None	N/A	Med	-	-	None	None	-	Do	Alt 916
2	Disconnect Input Cables to X-Unit	Med	N/A	Med	N/A	Med	5	3	Low	Low	4	-	Impractical
3	Provide TARC	Med	N/A	N/A	N/A	High	2	N/A	Low	High	5	Don't	No Pu, too big etc.
4	Use SST Only	Med	N/A	N/A	N/A	Low	1	N/A	High	None	1	Do	
5	Remove Thermal Batteries	Med	N/A	Med	N/A	Med	4	2	Low	Low	2		
6	"Spike" the X-Unit Capacitors	Med	N/A	Med	N/A	Med	3	1	Med	Med	3		

Chart 1. Retrograde Surety, B53-1 Safety Options

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DOE
D(3)

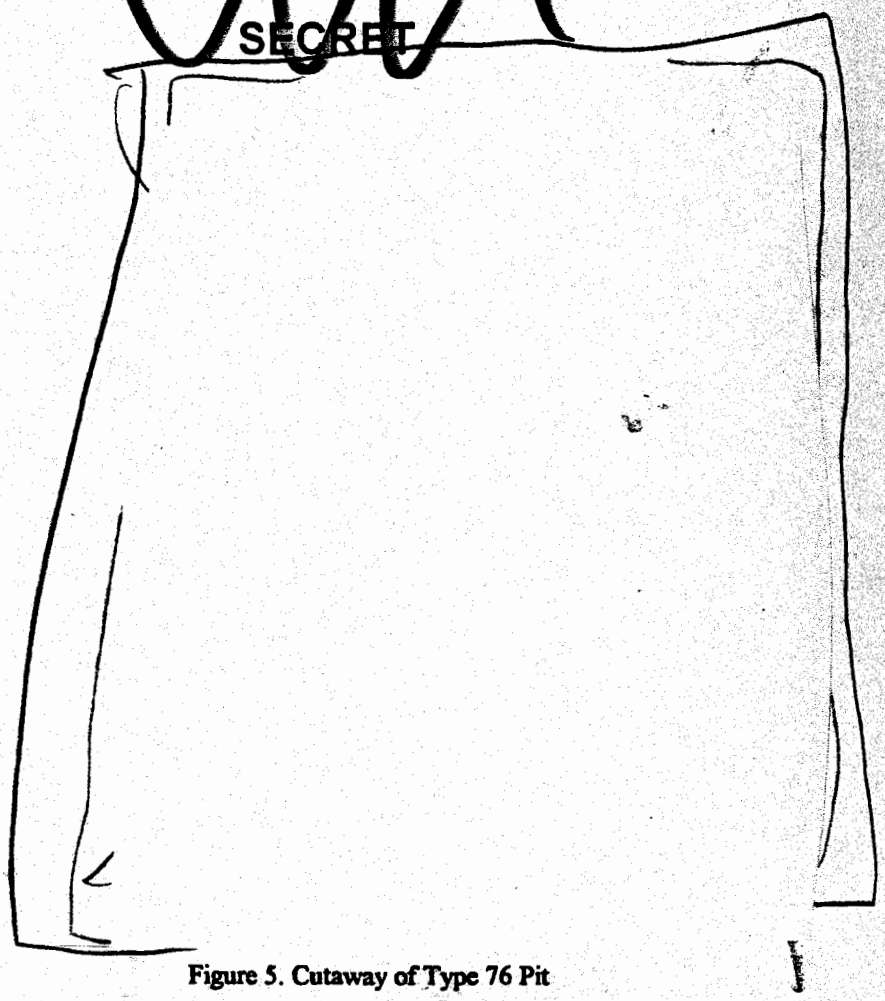
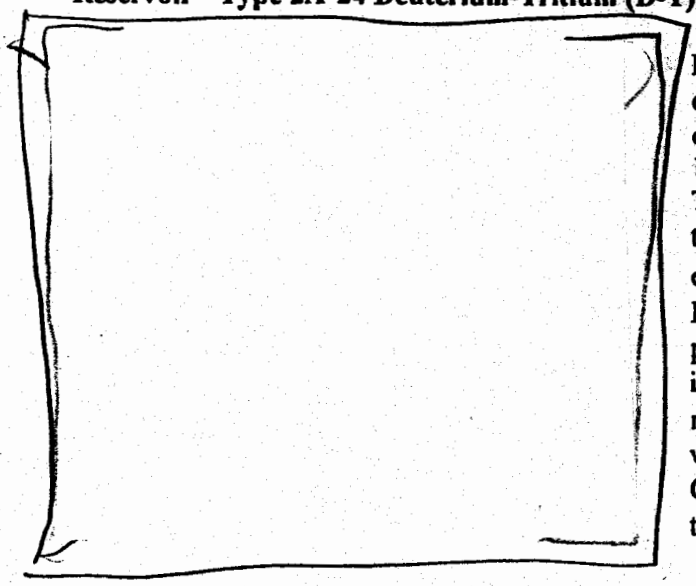


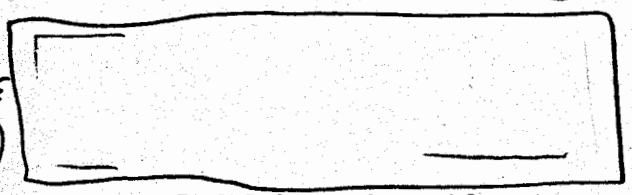
Figure 5. Cutaway of Type 76 Pit

Reservoir - Type 2A-24 Deuterium-Tritium (D-T) gas reservoir and valve assembly

DOE
D(3)



Each Type 1A squib contains an electro-exploding device (EED) that initiates 25 mg of lead styphnate, which in turn initiates 175 mg of Ball Powder (black powder). The Type 1A valve assembly contains a visible thermal plug that is designed to open in a fire environment (operating temperature 104°C). If the actuator squibs fire with the thermal plug open, the gas generated by the actuators is vented to the outside and the plunger will not be forced onto the reservoir and pit tubes with enough velocity to cut the tubes. Cutting these tubes is the only way of transferring the D-T gas to the pit.

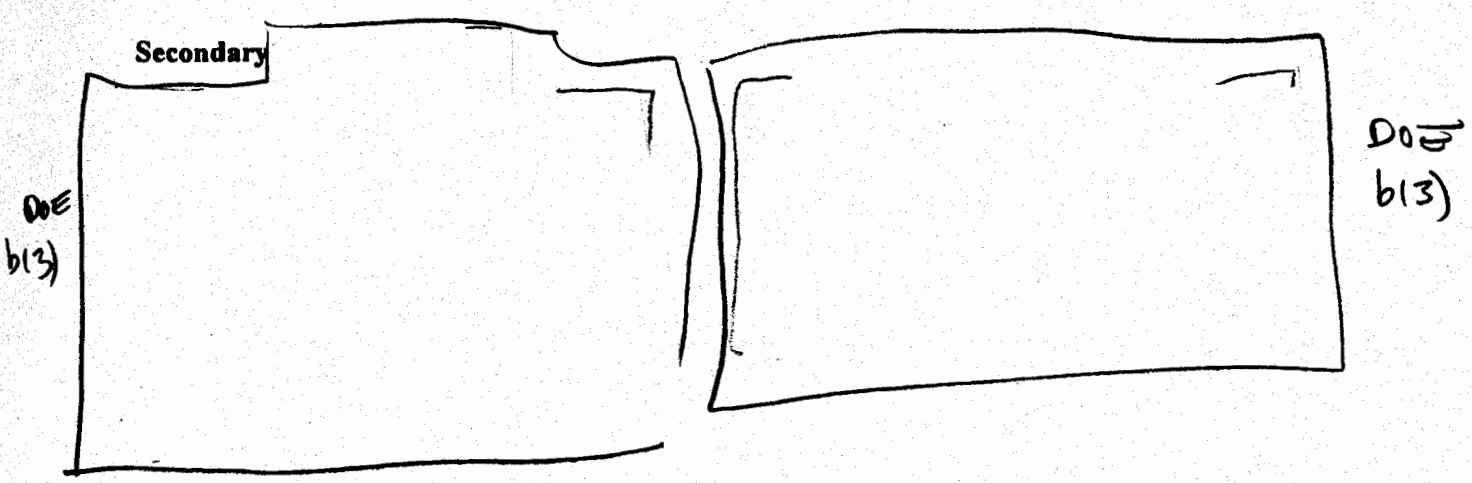


Cycle Life - The interval from the fill time to the time that the gas no longer meets the weapon yield certification because of Tritium decay. This life is used to determine the normal LLCE requirements.

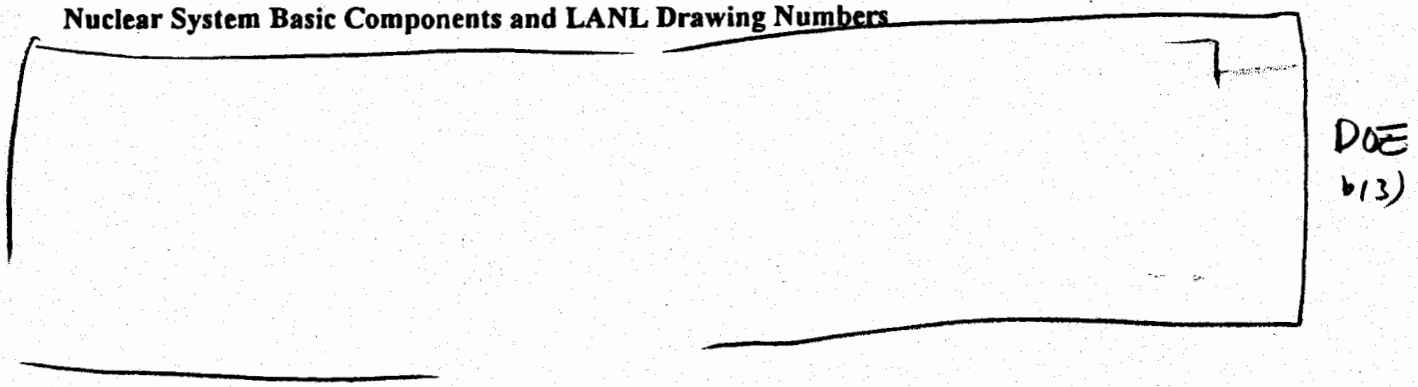
Extended Cycle Life - The interval from the fill time to the time that "unacceptable" yield degradation results from Tritium decay and helium generation. This time is greater than the cycle life and less than or equal to the limit life.

Limit Life - The interval from the fill time to the time that the structural integrity of the reservoir, including an appropriate factor of safety, may be compromised, resulting in an increased probability of a Tritium leak.

Stockpile Life - The total number of years that a reservoir can be exposed to a Tritium environment. It may limit the number of times a reservoir can be refilled.



Nuclear System Basic Components and LANL Drawing Numbers



2. Unique signal is provided by the AMAC to enable the MC2929 strong-link switch (requires approximately 25 seconds).

C. Weapon release:

1. Pullout rods are extracted from the MC1200A Fuzing System Control Selector:

   a. Pullout switches in the main thermal battery output lines closed.
   b. Pulse generators in the MC1200A are actuated initiating the MC1262 Thermal Battery Packs (fast-rise batteries) and MC1315 Sequential Timers (parachute timers).

2. MC1262 fast-rise batteries provide 12-volt power:

   a. T_0 contacts in MC1315 timers close.
   b. MC1315s initiate the MC1264 Thermal Batteries (main batteries).

3. 28-volt power is applied to contacts in the MC1268 Interval Timer.

4. [redacted]

   a. MC1315 parachute timer contacts close, completing circuits between the MC1262 fast-rise batteries and the MC1060 Electric Detonators in the automatic parachute deployment system.
   b. MC1315 provides a signal to cut the retardation parachute suspension lines, and the parachute deployment sequence occurs.

      (1) Automatic deployment cover is separated from the rear case section by mild detonating fuze (MDF) system.
      (2) Automatic deployment cover deploys the pilot parachute.
      (3) Pilot parachute deploys the retardation parachute.
      (4) [redacted]

      (5) [redacted]

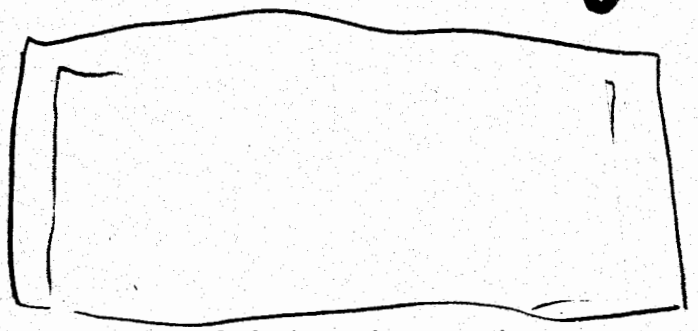
5. Laydown parachute drag causes the MC1268 Interval Timer (trajectory sensing device) to operate toward the armed position [redacted]

APPENDIX C

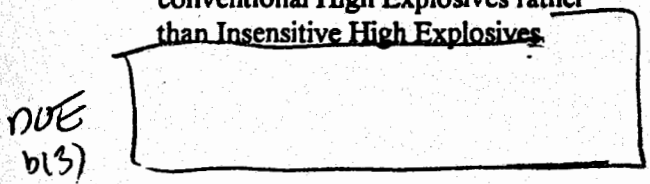
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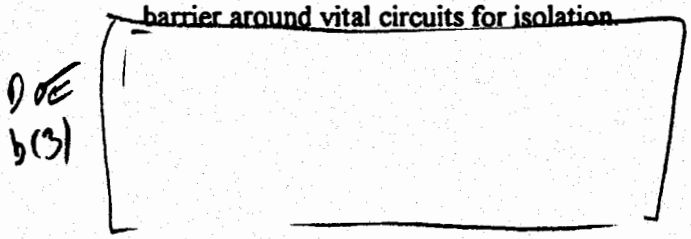
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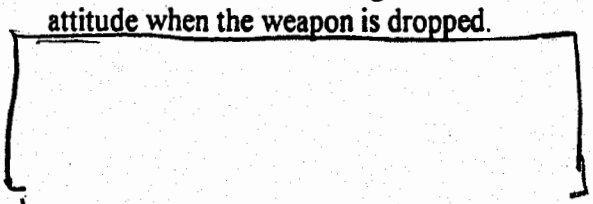
- The B53 physics package contains conventional High Explosives rather than Insensitive High Explosives.



- The B53 bomb was designed prior to the development of Enhanced Nuclear Detonation Safety (ENDS) concepts. The modification to the B53-1 utilizes a measure of ENDS, incorporating Power pack/shroud Zones and one hard-link (intent switch) and it does incorporate a barrier around vital circuits for isolation.



- The weapon contains an Environmental Sensing Device that is intended to block critical circuits until the intended use environment is sensed. The MC1268 interval timer senses a change in bomb attitude when the weapon is dropped.



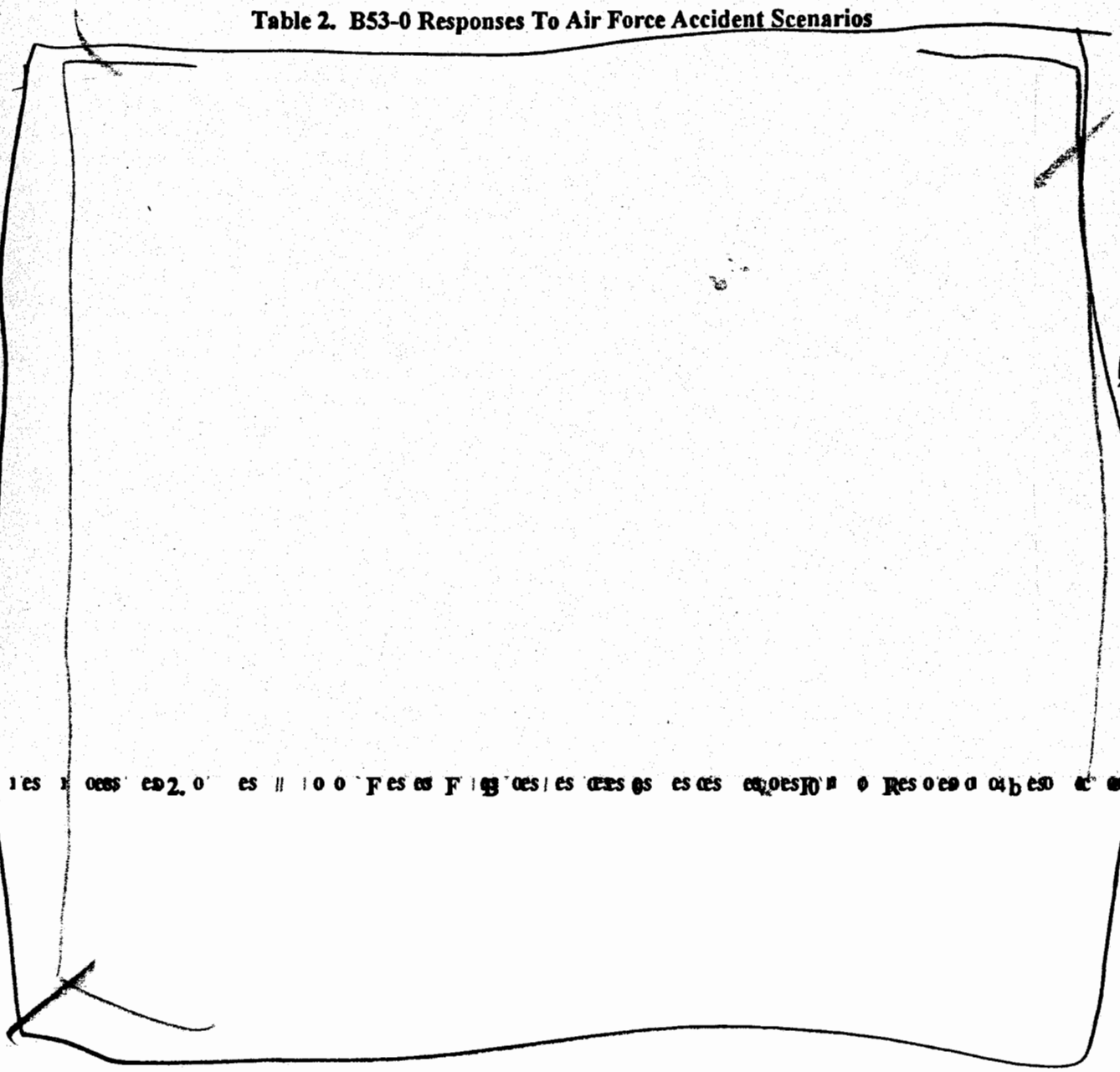
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APPENDIX D

TWG SUMMARY

Table 2. B53-0 Responses To Air Force Accident Scenarios



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Nuclear Weapon Data
Sigma 1

Critical Nuclear Weapon
Design Information
DoD Directive 5210.2 Applies

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Lawrence S. Germain

January 2, 1991

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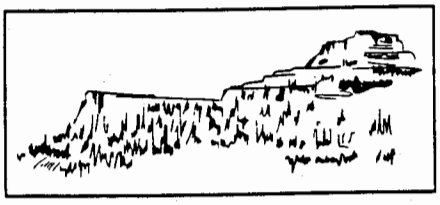
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PREFACE

This report is one in a CNSS series that surveys the development of nuclear weapons over the past forty-five years. The unifying themes throughout the series are the technical advances and failures associated with new weapon systems, and the creation of the stockpile.

Authors, titles, and report numbers are listed below.

William G. Davey, *Free-Fall Nuclear Bombs in the U.S. Stockpile (U)*, LA-11397

William G. Davey, *Nuclear Tests Related to Stockpiled Weapons Development (U)*, LA-11402

Lawrence S. Germain, *A Brief History of the First Efforts of the Livermore Small-Weapons Program (U)*, LA-11404

Lawrence S. Germain, *The Evolution of U.S. Nuclear Weapons Design: Trinity to King (U)*, LA-11403

Lawrence S. Germain, *A Review of the Development of Los Alamos Gnats and Tsetses before the 1958 Test Moratorium(U)*, LA-11749

Raymond Pollock, *The Evolution of the Early Thermonuclear Stockpile (U)*, LA-11748

Raymond Pollock, *A Short History of the U.S. Nuclear Stockpile 1945–1985 (U)*, LA-11401

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January 2, 1991

A BRIEF HISTORY OF THE FIRST EFFORTS OF THE LIVERMORE SMALL-WEAPONS PROGRAM (U)

Lawrence S. Germain

ABSTRACT (U)

This report, one in a series concerned with the history of nuclear-weapon research and development, describes the evolution of the design of fissile nuclear explosives at the Lawrence Livermore National Laboratory from its inception in 1952 to the nuclear testing moratorium in 1958. Nuclear tests are used as the unifying thread for the description of this evolution. The most important families of nuclear devices are identified, their evolution is outlined, and the stockpile weapons that resulted are indicated.

INTRODUCTION

Using the nuclear test program as a framework, this report describes the evolution of the design of fission explosive systems at the Livermore Laboratory up to the 1958 nuclear test moratorium. To understand this evolution one must understand the goals and limitations of the Livermore program. What were they trying to do?

Before 1952, all U.S. nuclear-weapons design was centered at Los Alamos (then the Los Alamos Scientific Laboratory; now the Los Alamos National Laboratory). The establishment of nuclear-weapons design activities at Livermore (then the University of California Radiation Laboratory; now the Lawrence Livermore National Laboratory) in 1952 offered the first opportunity for interlaboratory competition in this area. The Livermore fission-weapons program in those years was based on the assumption that it was not to duplicate active Los Alamos programs.

DOE b(3)

The official status of such a restriction is unclear, but it was the basis of operation at Livermore. At the same

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They all worked—some better than others—but several were of limited or no practical use.

It did serve, however, as a learning experience for the Livermore Small-Weapons Group—mostly green Ph.D.s who were complete novices at weapons design. They developed and used two-dimensional calculations, gained experience with the properties and fabrication of high explosives and fissile materials, and gained experience in nuclear field-test operations.

The story to be told is complex. In Part I, Livermore tests are described in chronological order because this gives the best indication of the development. This sequence can be confusing; thus, to assist the reader, the tests are described in Part II in terms of families that link together in a coherent way.

PART I: CHRONOLOGICAL DESCRIPTION

Teapot

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DoE b(3)

DoE b(3)

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DOE b(3)

DOE b(3)

The Livermore Small-Weapons Program thus organized a three-prong attack for operation Redwing.

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DOE b(3)

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DOE b(3)

Plumbbob

DOE b(3)

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DOE b(3)

DOE b(3)

DOE b(3)

DOE b(3)

DOE b(3)

DOE b(3)

DOE b(3)

DOE b(3)

DOE b(3)

[redacted]

DoE b(3)

Rainier was detonated on September 19, 1957, in a tunnel in Area 12. Rainier also gave its name to the mesa into which the tunnels were dug (Rainier Mesa) and to the volcanic rocks that cap that mesa (Rainier Mesa Tuff).

DoE b(3)

58A

As more and more weapons entered stockpile and came into the hands of people less knowledgeable about nuclear design, questions about the safety of nuclear weapons assumed more importance. One of the first questions to receive serious attention was one-point safety. The requirement was that no more than four pounds of nuclear yield should be produced as a result of the detonation at *any* one point in the HE, perhaps because four pounds is small compared with the amount of HE in the various devices.

The design physicist was repeatedly scolded for presenting unpromising results. He was urged to make the system work. As a result, he took the most optimistic view of each of the several areas of uncertainty in the design—too optimistic, as it turned out. It was only the nuclear test that revealed the overly optimistic approach. In the absence of nuclear testing, the design errors might never have been uncovered.

If there were no tests to keep the system honest, nuclear designers could be pressured into certifying designs that would not work.

DoE b(3)

As a consequence of these concerns, a series of one-point tests was conducted at the NTS called Operation 58A, which included two safety tests, Venus and Uranus, of Livermore devices. These were carried out between Operation Plumbbob and Operation Hardtack.

DoE b(3)

DoE b(3)

There were other Livermore tests in Operation Plumbbob to which the Livermore Small-Weapons Group did not contribute.

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DoE b(3)

DoE b(3)

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DoE b(3)

All were fired on Bikini Atoll. Nutmeg and Hickory were fired off the west end of Eneman (Tare) Island. Maple and Redwod were fired on a barge south of Lomilik (Fox) Island. Aspen was fired on a barge 4,000 ft west-southwest of Nam (Charlie) Island. Dogwood was fired 4,000 ft southwest of Enjebi (Janet) Island

DoE
b(3)

DoE
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DoE b(3)

DoE b(3)

DoE b(3)

Quince and Fig were fired on Runit (Yvonne) Island in Eniwetok Atoll as close to the ground as pos-

DoE b(3)

sible—the standoff of a few inches being required by the device designers to ensure that the presence of the ground did not perturb the implosion. This near-ground test was required to accommodate a fallout experiment conducted by Sandia.

DoE b(3)

DoE b(3)

DoE b(3)

There being no other NTS soil at hand, the Fig device was emplaced in the same location—radiation field or no. The Hamilton test was fired at the top of a 50-ft wood tower in Frenchman Flat, and Humboldt was fired atop a hastily constructed 25-ft wood tower in Area 3 of the NTS.

DoE b(3)

Laboratory interest in small, clean, and relatively clean warheads led to the testing of several unique systems.

DoE b(3)

DoE b(3)

DOE b(3)

DOE b(3)

PART II: FAMILIES

DOE b(3)

In these figures, arrows indicate the progression from one test to another. Many of these arrows are labeled with a number, and a brief description of the change indicated by that particular arrow is given.

AFAP

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time, the pie split went away. The laboratory directors found it increasingly difficult to reach accord, and the Washington bureaucrats could not countenance such important decisions being made in the field.

[redacted]

This writer was not present at the meeting and has heard two quite different stories about what happened.

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[redacted]

Strike 3—and the most important strike. The two laboratories decided to assign the project to Los Alamos. In those early days, there was a rather civilized process known as the pie split. Every year the two laboratory directors and their staffs would meet to decide which tasks would be undertaken by each of the laboratories. The Livermore management always returned from these meetings in exultation, feeling that they had not just taken most of the pie but also the crumbs on the table. However, as time went on the Los Alamos projects remained rock solid while the Livermore projects seemed to fall away, possibly because Los Alamos was taking the mainline projects and Livermore was taking the far out ones. In due

Bradbury said he was not interested. Several of his staff said they were interested. After a caucus, they agreed to the trade.

Story No. 2 is logical. Livermore badly wanted responsibility for a high-yield strategic warhead of their design. Only by having both the primary and secondary of a major strategic warhead identified as "designed in Livermore" could the Livermore Laboratory gain the status of a full partner in the nuclear-weapons design world. In fact, in subsequent years, Livermore made a special effort to gain responsibility for strategic nuclear weapons.

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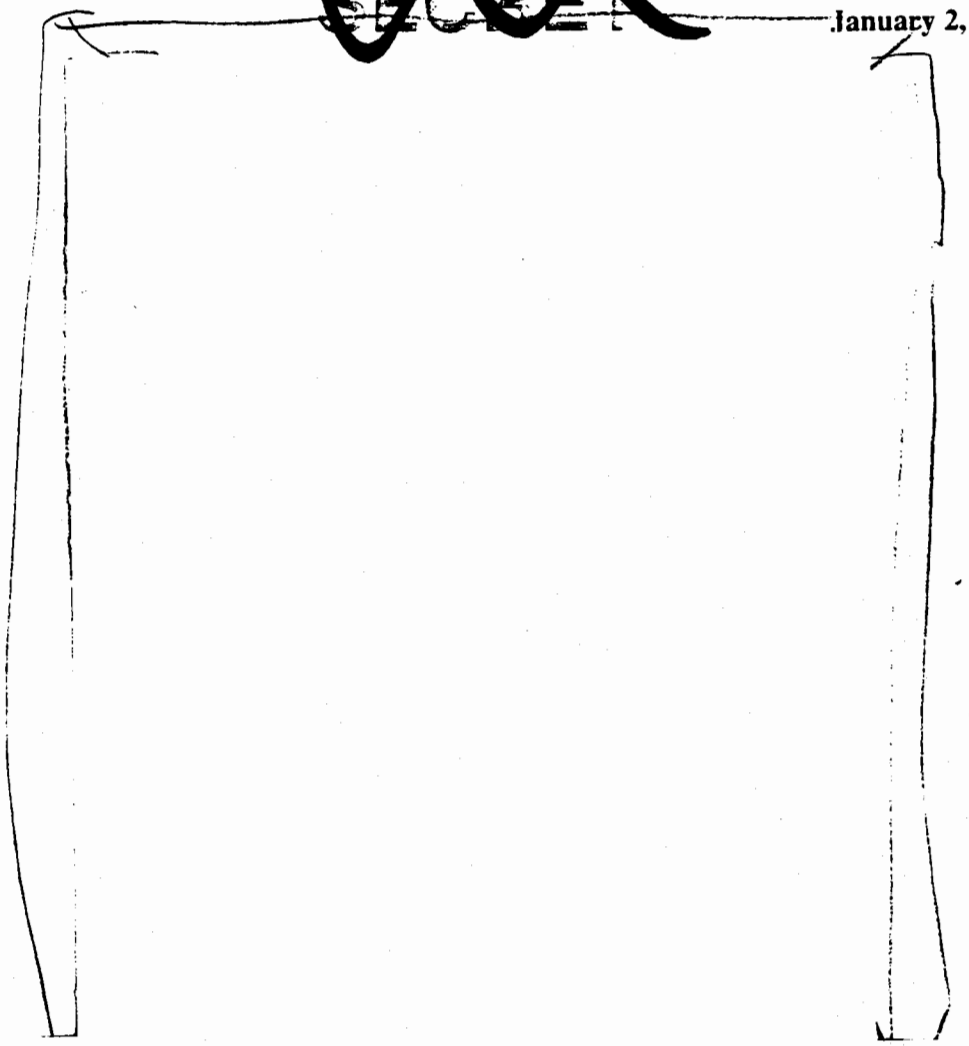
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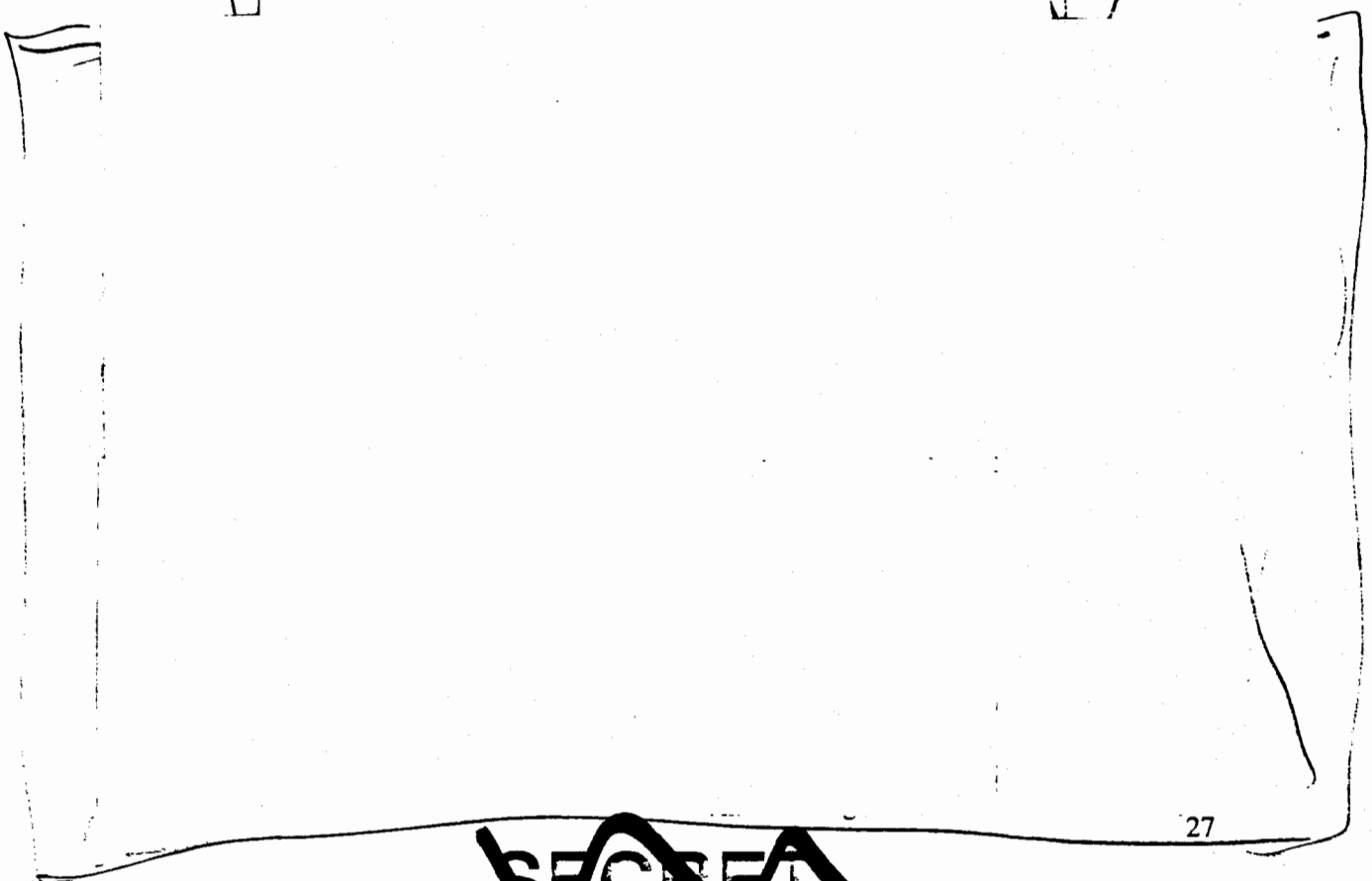
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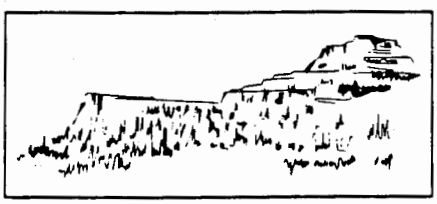
A Review of the Development of Los Alamos Gnats and Tsetses before the 1958 Test Moratorium (U)

Lawrence S. Germain

Nuclear Weapon Data
Sigma 2

Critical Nuclear Weapon
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Lawrence S. Germain retired from the Los Alamos National Laboratory in 1985 after thirty years of experience in weapons design and testing in the national laboratories—twenty years at Lawrence Livermore National Laboratory and ten years at Los Alamos. He received a Ph.D. in physics from the University of California, Berkeley, in 1949 and taught physics for four years at Reed College, Portland, Oregon, before joining Livermore. Much of this report is drawn from the author's memory, and many of the opinions expressed reflect his personal recollections.

The first draft of this report was written in 1988, and the information in the report does not reflect events or research since 1988.

LA-11749

January 2, 1991

A REVIEW OF THE DEVELOPMENT OF LOS ALAMOS GNATS AND TSETSES BEFORE THE 1958 TEST MORATORIUM (U)

Lawrence S. Germain

ABSTRACT (U)

This report, one in a series concerned with the history of nuclear-weapons research and development, outlines the evolution of the Los Alamos Gnat and Tsetse systems before the 1958 test moratorium.

INTRODUCTION

The evolution of nuclear fission explosives at Lawrence Livermore National Laboratory (then the University of California Radiation Laboratory) from its inception in 1952 until the onset of the nuclear test moratorium in 1958 has been treated in Lawrence S. Germain, "A Brief History of the First Efforts of the Livermore Small-Weapons Program (U)," Los Alamos National Laboratory Report LA-11404, May 1990 (SRD).

DOE (b)(3)

Gnat

DOE (b)(3)

DOE b(3)

DOE b(3)

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DOE b(3)

SUMMARY OF FAMILIES

The premoratorium family histories of the two systems discussed in this report are shown in Figs. 1 and 2.

DoE b(3)

DoE b(3)

Tsetse

DoE b(3)

Gnat

DoE b(3)

DoE b(3)

DoE b(3)

Timetable of Mk 54 Events

FALCON and DAVY CROCKETT Warhead Application

1958 Interest develops in lightweight, low-yield warheads for application to FALCON air-to-air missile and DAVY CROCKETT ground-to-ground recoilless rifle.

(b)(1), (b)(3)

1/15/59 Division of Military Application transfers nuclear part of the project to Los Alamos. XW-51 Warhead renamed the XW-54.

10/21/59 Proposed ordnance characteristics of the XW-54 Warhead presented to Special Weapons Development Board and accepted.

12/59 Mk 54 Mod 0 Warhead (FALCON Application) design released.

4/15/60 Mk 54 Mod 1 Warhead design released. This warhead contained no environmental sensing device and was canceled before production.

11/60 Mk 54 Mod 2 (DAVY CROCKETT Application) design released.

4/28/61 Early production of Mk 54 Mod 0 and Mod 2 Warheads.

Special Atomic Demolition Munition (SADM)

2/20/58 Assistant Secretary of Defense notifies United States Atomic Energy Commission that Army has requested feasibility study of an SADM.

(b)(1), (b)(3)

11/10/59 Sandia proposes SADM design to Division of Military Application.

4/7/60 Assistant Secretary of Defense requests Atomic Energy Commission to develop an SADM.

7/26/60 Military characteristics for SADM approved by Military Liaison Committee.

9/5/61 Military characteristics amended to require underwater pressure case.

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Mid-1962 Timer development problems cause schedule delays.

(b)(1), (b)(3)

4/63 Mk 54 Mod 1 SADM design released.

8/64 Mk 54 Mod 1 SADM enters stockpile.

6/65 Mk 54 Mod 2 SADM enters stockpile.

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History of the Mk 54 Weapon

FALCON and DAVY CROCKETT Warhead Application

(b)(1), (b)(3)

The FALCON or GAR-11 was an air-to-air missile being engineered by the Hughes Aircraft Company for the Air Force. The DAVY CROCKETT was a ground-to-ground system designed to fire a projectile from a recoilless rifle and was being developed by the Army.[1]

(b)(1), (b)(3)

It was felt that the warhead would be compatible with the DAVY CROCKETT system and be able to withstand the acceleration produced by the recoilless rifle.

(b)(1), (b)(3)

It was felt that production FALCON warheads might be available by February 1961.

Instrumentation errors were discovered on two flights, and aircraft troubles developed on two others, but the rest of the tests were completely successful.[26]

Report SC4632(WD), Final Development Report for the Mk 54 Warhead Systems, was accepted by the Design Review and Acceptance Group December 14, 1961 and forwarded to the Division of Military Application February 19, 1962. The report noted that the warhead was 10.862 inches in diameter, 15.716 inches long, and weighed about 50.9 pounds. The design included a motor-driven chopper-converter system and contained no power supply.

(b)(1), (b)(3)

The electric system consisted of a firing set and detonator assemblies. This system was a standard chopper-converter design largely using off-the-shelf components. It contained no power source, no one-shot devices, and no components requiring field monitoring, although the environmental sensing devices could be monitored.

(b)(1), (b)(3)

These components were interconnected by printed wiring, and the entire assembly was encapsulated in foamed plastic in a fiberglass housing.

Since the fiberglass housing was electrically nonconductive, it was coated with a conductive lacquer to provide an electrostatic shield from warhead connector to rear cap. This coating was requested by the Department of Defense due to the susceptibility of the fuze to radiated electrical noise generated by the firing set. A connector cover and seal were installed on the

warhead connector after the firing set was assembled to the rear cap of the warhead case.

(b)(3)

Enviromental sensing devices were placed in the input lines to the converter transformer, and these devices remained open during warhead storage and handling, and closed during a launch environment.

In the Mk 54 Mod 0 Warhead for the FALCON application, the warhead was installed in the missile section with its longitudinal axis offset about 1/8 inch to allow room for missile cabling. The FALCON was an air-to-air, semi-active radar homing missile, designed to be launched from F-102A aircraft. The missile diameter was 11.4 inches, length 85 inches, wingspan 24.5 inches, and weight 260 pounds at launch and 200 pounds after motor burnout. The rocket motor produced a total impulse of about 12,900 pound-seconds, which applied an acceleration of 20 to 40 g's to the missile, depending on launch conditions. After rocket-motor burnout, the missile tracked the target on a collision course. The guidance system homed the missile on a target that was

either radar-illuminated by the launch aircraft or by electronic countermeasures emitted by the target.

The missile had a proximity fuze with an operating radius of about 100 feet for a 40-square-foot target. The antenna pattern was in a plane perpendicular to the longitudinal axis of the missile. The output of the proximity fuze was connected to the fuze relay through a safing and arming device.

(b)(3)

The warhead power source in the fuze consisted of two 28-volt thermal batteries. The batteries were initiated about 0.5 second prior to launch and came up to voltage about 1 second after initiation. Battery output was applied to the warhead through the safing and arming device at arm time. This device was a switching mechanism that provided warhead arming by connecting the power supply to the warhead connector and preparing the warhead for firing by connecting the proximity fuze to the fuze relay. This latter device provided switch closure between firing capacitors and pulse transformers of the firing set.

The safing and arming device was latched in the SAFE position until about 1.5 seconds prior to launch. The mechanism had two sets of cam-operated contacts. One set, which was normally open, armed the warhead, and the other set, which was normally closed, disabled the warhead after guided flight in the event of a miss. Both sets were committed during launch acceleration after an environment of about 14 g-seconds.

During the drag phase of deceleration, a spring force developed during acceleration drove the switches to the ARM and DISABLE positions through escapement timers. The escapement time depended on the spring force developed during acceleration and on the deceleration experienced by the missile after motor burnout.

(b)(1), (b)(3)

(b)(1), (b)(3)

The arm contacts were spaced to provide warhead power 0.3 to 0.5 second prior to connecting the fuze relay to the proximity fuze.

(b)(1), (b)(3)

The Mk 54 Mod 2 Warhead was designed for the DAVY CROCKETT, the Army's Battle Group Atomic Delivery System. There were two DAVY CROCKETT systems; the XM28, a lightweight, three-man portable system using a 120mm recoilless rifle with a range of 350 to 2000 meters; and the XM29, a vehicle-transported system using a 155mm recoilless rifle with a range from 350 to 4000 meters. Each system fired an XM388 projectile.

The XM388 projectile included the warhead, rear body and fin assembly, and fiberglass windshield. The projectile had a diameter of 11 inches, length of 30 inches, and weight of 76 pounds.

(b)(3)

A manually operated arm/safe switch interrupted the power supply to the warhead when in the SAFE position. The fuze incorporated a mechanical timer to set the time of flight and to provide safe-separation distance. The fuze contained thermal batteries activated at missile launch to supply power to the warhead and squib switches to close warhead firing circuits.

(b)(1), (b)(3)

At launch, the fuze timer mechanism and the inertial switches in the warhead were actuated. Concurrently, the 28-volt thermal batteries in the fuze were activated, and this action started chopper motors in the firing set. When the preset time was reached, four sets of switches in the timer mechanism closed. Closure of two sets of these switches armed the warhead and initiated the X-unit thermal batteries. Closure of the other two sets of switches connected the X-unit thermal batteries to the fuze. Upon sensing

the selected burst height, a set of squib switches closed and triggered the firing set.[23]

Special Atomic Demolition Munition

The Assistant Secretary of Defense notified the United States Atomic Energy Commission, February 20, 1958, that the Army had recently evaluated atomic demolition devices. There was a requirement for a small and light munition that could be carried by one man. This project, which had been initially called the Tactical Atomic Demolition Munition, would be known as the Special Atomic Demolition Munition (SADM), and a feasibility study was authorized.[27]

(b)(1), (b)(3)

The project was delayed while attention was being given to the design of the XW-54 Warhead for FALCON and DAVY CROCKETT applications, although Sandia informed Albuquerque Operations Office, April 23, 1959, that the XW-54 could be considered for SADM application.[6]

Sandia forwarded a proposal for a nuclear demolition munition to the Division of Military Application November 10, 1959. A modified XW-54 Warhead was proposed, containing an integral fuze compactly packaged in a lightweight sealed waterproof housing, and it was suggested that the entire munition be procured and fabricated by the Atomic Energy Commission. The design would provide a rugged munition small enough for covert missions and capable of being rapidly prepared for firing under conditions of high operational stress where time was critical.[30] It was noted that the only existing munition that approached these requirements was the T-4, an adaptation of the Mk 9 gun-type weapon. However, the T-4 was packaged in four 40-pound sections and required four men for delivery. It was felt that an XW-54 SADM would have a diameter of 11-7/8 inches, length of 17-1/2 inches, and weight of 56 pounds including carrying case.[31]

the dial was protected by a cover sealed with an O-ring. The safed or armed condition of the firing set could be observed through a window in the lock-secured cover.

(b)(1), (b)(3)

The container had a negative buoyancy of about 5 pounds in water and was provided with an external arming device that permitted underwater arming.

(b)(1), (b)(3)

(b)(1), (b)(3)

With the control in the ARM position, the time-delay setting could not be changed. When the arm/safe control was returned to the SAFE position, all safety features and interlocks were reengaged.

(b)(1), (b)(3)

Upon completion of manual arming and after the preset time-delay interval, the timer provided firing signals which activated the electric detonator. This detonator created a shock wave that actuated the explosive plane-wave

generator and created a high-energy planar shock wave that impinged on the transducer. This resulted in a rapid stressing of the ceramic transducer and produced a high-peak-energy pulse that initiated the high-explosive/nuclear system detonators. The resultant implosion of the high explosive initiated the nuclear reaction.[54]

A Mk 54 Mod 2 SADM, with the same diameter and length attained early production in June 1965.

(b)(1), (b)(3)

The weight was increased to 70 pounds.[55]

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January 1968

RS 3434/36
AEC ATOMIC WEAPON DATA

HISTORY OF THE MK 55 WARHEAD (U)

SC-M-68-47

SC-M-68-47
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Weapon Systems

Information Research Division, 3434

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Timetable of Mk 55 Events

9/19/56	Assistant Secretary of Defense requests Atomic Energy Commission to cooperate with the Navy in a feasibility study of a nuclear warhead for a submarine-launched torpedo. Study conducted throughout 1957 recommended development of SUBROC, a rocket-propelled torpedo for attack of enemy submarines.
1/17/58	Bureau of Ordnance requests cooperation of the Atomic Energy Commission in feasibility study of warhead for SUBROC.
1/22/58	Special Weapons Development Board urges support of SUBROC warhead.

(b)(1), (b)(3)

1/6/59	Assistant Secretary of Defense requests Atomic Energy Commission to develop SUBROC warhead.
2/17/59	Military Liaison Committee releases set of military characteristics for SUBROC warhead.
4/17/59	Designation of XW-55 assigned to SUBROC warhead.
8/31/59	Sandia forwards development program definition of XW-55 Warhead to Albuquerque Operations Office.
10/61	Sandia releases proposed ordnance characteristics of XW-55 Warhead.

(b)(1), (b)(3)

3/20/63	Mk 55 Warhead design released.
1/64	Mk 55 Warhead achieves production.
7/23/64	Final development report of Mk 55 Warhead accepted by the Design Review and Acceptance Group.

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History of the Mk 55 Warhead

By the fall of 1956, design was in progress on the Mk 44 depth-bomb warhead, designed for surface-ship attack of enemy submarines. Subsequently, the possibility of developing a warhead that could be launched from one submarine against another was raised and, September 19, 1956, the Assistant Secretary of Defense requested the United States Atomic Energy Commission to cooperate with the Navy in a feasibility study of a nuclear warhead for such a submarine-launched torpedo.[1]

This study was conducted during 1957. The missile was called SUBROC, and was a rocket-propelled missile launched into the atmosphere from a submerged attacking submarine and designed to attack a target submarine located underwater at some distance.

(b)(1), (b)(3)

In response to a teletype from the Division of Military Application, Sandia noted, December 26, 1957, that warheads could be supplied by March 1960. However, complete design release could not be made until flight tests had provided adequate proof of warhead and missile system compatibility. These flight tests would start in the fall of 1959 and continue into 1960. It was felt that the design might be released by December 1959, and that production warheads would be available by October 1960.

Warheads for the first two submarines would be produced in accordance with design information available in August 1959. These units would not be of full production quality since flight test data would not be available, although much of the critical laboratory testing would have been completed.

(b)(1), (b)(3)

RESTRICTED DATA SECRET

UNCLASSIFIED

The Special Weapons Development Board met January 22, 1958 and listened to a presentation on the proposed SUBROC weapon. It was pointed out that the United States was committed to the economic and military support of the 15 member nations of the North Atlantic Treaty Organization (NATO), located on four continents. Since this support required maintenance of seaborne and logistic links, the collective security of NATO could be seriously jeopardized by an aggressive enemy submarine campaign. There was thus an urgent need for an effective anti-submarine warfare (ASW) weapon system.

Submarines appeared to be the most suitable delivery vehicles for such weapons, but available submarine-launched weapons had only limited effectiveness. Torpedos were reasonably efficient only to a range of about 10,000 yards (less than 6 miles). High-speed torpedos were noisy and alerted their targets. Long-range, quiet torpedos required command inputs during travel to target, and were relatively slow. It was felt that a SUBROC-type missile would greatly enhance the ASW capabilities of the Navy's submarines.[4]

Meanwhile, the Bureau of Ordnance, in a letter dated January 17, 1958, noted that the SUBROC study had been completed and requested the cooperation of the United States Atomic Energy Commission in a feasibility study of a suitable warhead.

(b)(1), (b)(3)

(b)(1), (b)(3) The outside diameter would be 13 inches, length 42-1/8 inches, and weight 370 pounds. Reasonable variations in these parameters would be acceptable in order to develop an optimum missile/warhead combination.

(b)(3)

The Division of Military Application, in forwarding the military characteristics, referred to the moratorium on nuclear testing. If dimensional limitations could not be satisfied without further testing, the Military Liaison Committee would be informed concerning those parameters that could be provided without such testing.[9]

Development was authorized for the SUBROC warhead application March 24, 1959, and Sandia notified Albuquerque Operations Office April 17, 1959 that the designator XW-55 had been assigned to the program.[10] Plans were made for air-gun and drop-tests to certify the structural adequacy of the warhead for water entry. A relatively small number of flight tests would be required, and full-scale firings would be made in early 1960.[11]

Sandia forwarded the development program definition on the XW-55 Warhead to Albuquerque Operations Office August 31, 1959. The warhead would fulfill requirements for a 450-pound warhead for the SUBROC missile. The military characteristics had specified a warhead weight of 370 pounds, but it was found that missile stability required that additional weight be placed as far forward in the missile as possible, and the Bureau of Ordnance requested that a suitable change be made to the military characteristics.

(b)(1), (b)(3)

(b)(1), (b)(3)

The design would be released in mid-1962, and early production was scheduled for the second quarter of calendar 1963. The warhead would be operational by July 1963.

The warhead would have a maximum diameter of 13 inches and maximum length of 39.4 inches.

(b)(1), (b)(3)

The firing system would include a chopper-converter, capacitor-type X-unit, and acceleration-sensing handling safety devices. The warhead would be sealed and would require only continuity monitoring in stockpile or field.

The SUBROC was designed to be fired from a Navy standard 21-inch-diameter torpedo tube. The missile would have a maximum diameter of 21 inches, length of 246 inches, gross weight of 4000 pounds, re-entry depth-bomb weight of 900 pounds, and a range from 5 to 35 nautical miles. Velocity at water impact at the maximum range would be about 1500 feet per second and the missile would have a solid-fuel propulsion system.

Due to high-load-factor requirements, the case would be built of high-strength steel having a yield point of about 160,000 pounds per square inch.

(b)(1), (b)(3)

The military characteristics were amended by the Military Liaison Committee November 12, 1959. The weight of the warhead without frangible nose section was increased to 450 pounds, including ballast if necessary. The warhead would be compatible with such other applications (in addition to the SUBROC) as might be authorized by the Department of Defense.[13]

By April 1960 it had been decided that a g-second environmental sensing device would provide maximum warhead safety. Although the weapon was being designed specifically as an underwater-launched air-trajectory missile for depth-charge application, it was felt that the warhead should also have a capability for air-burst detonation, or operation independent of the water-entry environment. Thus, an environmental sensing device actuated by launch environment was desired. Devices currently available did not meet SUBROC requirements, with its relatively low launch acceleration.[14]

Sandia published Report SC4818(WD), XW-55 Warhead, Proposed Ordnance Characteristics, in October 1961.

(b)(1), (b)(3)

The report had been previously reviewed by the Design Review and Acceptance Group and found to be satisfactory with the exception of monitoring provisions.

(b)(3)

The report noted that design release was slated to start in January 1962 and to be completed during June 1962.

(b)(1), (b)(3)

The trajectory would be

guided during both boosted and unboosted phases.

(b)(1), (b)(3) Upon re-entering the water, the missile would sink to a preset depth and detonate.

The missile weighed about 4200 pounds, including a 3300-pound motor section. The depth-bomb section contained a warhead, adaption kit, auxiliary power unit, and guidance and control system. The control system used fins to guide the missile after the depth bomb separated from the rocket motor. To provide enough fin area, the diameter of the depth bomb was restricted to 13 inches. The depth-bomb section weighed about 900 pounds. An aerodynamic nose fairing, attached to the front of the ballistic case, would be wiped off at water entry, exposing a flat nose which provided underwater stability.

(b)(3)

Shock tests simulating water entry at 1420 feet per second were reported November 13, 1961. Results demonstrated that the weapon case could withstand this shock without damage.[16]

Field Command notified Sandia, November 22, 1961, that the proposed ordnance characteristics had been reviewed with representatives of the interested Services.

(b)(1), (b)(3)

However, this deviation was temporarily accepted, pending results of further tests. There was also a requirement for physical separation of a vital component from the warhead. Inasmuch as the design included multiple safety devices, the Navy felt that the intent of the requirement had been met. It was noted that

radiation from the warhead should not be more than 0.1 Rem per week, but this figure had been exceeded, and the Navy was requested to restudy the requirement. The design was meanwhile considered acceptable to the Department of Defense.[17]

(b)(1), (b)(3)

The Lawrence Radiation Laboratory notified the Division of Military Application June 9, 1962 that the XW-55 Warhead, while in storage, emitted gamma-ray and neutron radiation in an amount somewhat greater than allowed by the military characteristics. The Naval Ordnance Laboratory suggested that shielding, as well as a security cover, be placed on each warhead. This added structure would weigh about 400 pounds, and it would be necessary to repeat an extensive series of vibration and shock tests, and possibly redesign the warhead.

Since the radiation level decreased rapidly with distance from the warheads, it was felt that only the warheads adjacent to the passageway would contribute significantly to radiation in the passageway, and it was recommended that the passageway be provided with appropriate shields, or that no warheads be stored next to the passageway.[19]

The warhead was tested on a hydraulic centrifuge in the launch orientation to a linear acceleration of 10 g's, and no structural damage was noted.[20] A shock test was reported September 21, 1962, which simulated the environment of a depth-charge attack made on a submarine carrying the XW-55 Warhead. Again, no damage was noted.[21] Other successful tests included roll acceleration, shipping vibration, dynamic heating, thermal cycling and shock, vibration of warhead and missile, electrical system, simulated water entry, hydrostatic, bottom impact and depth-charge shock, and cookoff tests.[22]

By July 1962 it was learned that the operational availability date of the SUBROC missile had been postponed from November 1963 to April 1964.[23] Accordingly, early production of the XW-55 Warhead was deferred to January 1964.

The Mk 55 Warhead was design released March 20, 1963.

(b)(1), (b)(3)

Field Command notified Sandia April 30, 1963 that Report SC4854(WD), Mk 55 Mod 0 Interim Development Report, had been reviewed in coordination with representatives of the Services.

(b)(1), (b)(3)

It was considered that the design was acceptable to the Department of Defense.[25]

The Mk 55 Mod 0 Directive Schedule was published July 31, 1963, and authorized quantity production and stockpiling. Early production of the warhead was achieved in January 1964.[26] In accordance with a request from the Department of Defense, the warhead weight was ballasted to 465 pounds rather than 450 pounds. The overall length of the warhead without frangible nose section was 39.283 inches, instead of the specified 39 inches.

Report SCL-WD-64-28, Mk 55 Mod 0 Final Development Report, was presented to and accepted by the Design Review and Acceptance Group July 23, 1964.

(b)(1), (b)(3)

Timetable of Mk 56 Events

4/4/58	Assistant Secretary of Defense requests United States Atomic Energy Commission to cooperate in feasibility study of 330- and 550-pound warheads for the MINUTEMAN missile.
5/5/58	Feasibility study group recommends development of two warheads.
12/58	Division of Military Application reconvenes feasibility study group to consider a 600-pound warhead.
3/2/59	Feasibility study group reports that a suitable 600-pound warhead can be provided.

(b)(1), (b)(3)

9/15/59	Military Liaison Committee releases set of military characteristics for the MINUTEMAN warhead.

(b)(1), (b)(3)

11/20/59	Division of Military Application assigns development nomenclature of XW-56 and XW-56-X1 to the above designs.
12/24/59	Sandia issues development program definition of the XW-56 Warhead.

(b)(1), (b)(3)

8/60	Sandia publishes proposed ordnance characteristics of XW-56 Warhead.
10/13/60	Director of Defense Research and Engineering selects 600-pound XW-56-X1 design for MINUTEMAN.
12/1/60	Division of Military Application cancels XW-56 Warhead program. XW-56-X1 to continue and be called, in production, the Mk 56 Mod 1 Warhead.

3/24/61	Lawrence Radiation Laboratory and Sandia-Livermore forward development program definition of XW-56-X1 to Albuquerque Operations Office.
9/61	Production of XW-56-X1 Warhead authorized.

(b)(1), (b)(3)

12/18/62	XW-56-X2 Warhead interim development report accepted by Design Review and Acceptance Group.
3/63	Mk 56 Mod 1 Warhead final development report released. Early production attained.

(b)(1), (b)(3)

10/63	XW-56-X3 Warhead preliminary development report issued. Redesign provides hardening against weapon blast effects. (Product Mod 3)
8/64	Early production of Mk 56 Mod 2.
9/64	Mk 56 Mod 1 supplement to final development report notes that the warhead safing system has been improved.
4/65	Mk 56 Mod 2 Warhead final development report released. Warhead hardened against blast effects.
3/66	Mk 56 Mod 2 supplement to final development report notes that the stockpile life of the neutron generator meets requirements of the military characteristics.
5/5/66	Division of Military Application requests hardening of warhead against effects of high-energy X-rays.
12/66	Design release of Mk 56 Mod 3 Warheads.

2/67	Early production of Mk 56 Mod 3 Warheads.
3/21/67	Sandia proposes additional hardening of warhead against X-rays.
5/24/67	Design release of Mk 56 Mod 4 Warheads.
5/67	Early production of Mk 56 Mod 4 Warheads.

History of the Mk 56 Warhead

The Mk 56 was a program to provide a thermonuclear warhead for Weapon System WS-133A, whose vehicle was a three-stage, solid-propellant, intercontinental ballistic missile called MINUTEMAN, designed and manufactured by Boeing Airplane Company for the United States Air Force.

The MINUTEMAN missile was a second-generation system with more advanced characteristics than ATLAS and TITAN. A study group had suggested in 1956 that improvements could be made through the use of solid-propellant engines, which would reduce missile size, ground support equipment, numbers of operating personnel, and would increase missile readiness.

(b)(1), (b)(3)

The MINUTEMAN would be about 5-1/2 feet in diameter, 57 feet long, and weigh 65,000 pounds. It would be launched vertically from an unmanned, underground silo-type launcher, and missile stability provided by controlling the rocket nozzle direction.

(b)(1), (b)(3)

Development of the missile was approved by the Department of Defense February 28, 1958, and a study was released March 11, 1958.

This study indicated that two sizes of re-entry vehicles (and nuclear warheads) would be needed to achieve operational flexibility, and the Assistant Secretary of Defense, April 4, 1958, requested the United States Atomic Energy Commission

to cooperate with the Department of Defense and the Air Force in a feasibility study of two MINUTEMAN warheads, one weighing in the neighborhood of 330 and the other 550 pounds. It was noted that these warheads would be required in large quantities. It was requested that the yields be the maximum achievable in the weights specified and that the systems have an operational deployment date of mid-1962.[1]

The feasibility study group met May 5, 1958 and, having been requested to quickly complete the task, finished the study in one day. It was felt that the lighter device could be developed as a modification of the Mk 50 NIKE ZEUS warhead of the Los Alamos Scientific Laboratory and that a heavier design could be provided by partial rework of the XW-47 POLARIS warhead of the University of California Radiation Laboratory. There appeared to be no unusual interprogram effects concerning application of either design to the MINUTEMAN missile, and it was felt that the operational deployment date could be met.[2]

Little action was taken during much of 1958, due to lack of MINUTEMAN funding.

(b)(1), (b)(3)

Results of this second feasibility study were published March 2, 1959. It was reported that the weight of the XW-47 could be reduced, and that several other Radiation Laboratory designs could be considered for an operational availability date of mid-1963. It was noted that the United States had suspended nuclear testing October 31, 1958 and, as a result, heavy emphasis was placed on designs that could be certified without full-scale test.[3]

The Air Force Special Weapons Center sent a teletype to Sandia March 15, 1959, noting that the Air Staff was considering possible acceleration of the MINUTEMAN

program and requesting the earliest availability date of a MINUTEMAN warhead.[4] Sandia replied, March 20, 1959, stating that the most serious restraint on warhead availability would be the requirement for completion of a group of six successful missile-warhead flight tests about a year before the warhead could be stockpiled. If the XW-47 Warhead were used without change, these flight tests could be completed by December 1959, but if the warhead were modified, the flight tests might extend for another year.

(b)(1), (b)(3)

Subsequently the Joint Chiefs of Staff, August 5, 1959, established a requirement for a MINUTEMAN warhead with a diameter of 20 inches, length of 60 inches, weight of 600 pounds, and the highest yield obtainable within these parameters.

(b)(1), (b)(3)

AVCO Manufacturing Corporation would design and produce the re-entry vehicle.

(b)(1), (b)(3)

The Military Liaison Committee released a set of warhead military characteristics September 15, 1959. The weapon would provide air or ground burst, be sealed, and require a minimum of servicing and component replacement. It would be capable of being left unattended for long periods of time, and its storage life would be at least 3 years.

(b)(1), (b)(3)

The warhead would contain no primary source of power, unless the use of a ferromagnetic X-unit became necessary. At least one arming device that would serve as a safety feature was required to sense the postlaunch environment, and this component would be installed in the warhead so as to minimize the possibility of nuclear detonation by sabotage.[3]

The following priorities would be observed: Safety from nuclear disaster to friendly installations, acceptable reliability, operational simplicity, ease of maintenance, and invulnerability to ~~neutron radiation~~ nuclear countermeasures. If the warhead system were such that, when armed, energy was stored awaiting a firing signal for detonation, a device would be required to safely dissipate the energy in a minimum time, not over 10 minutes, and not to interfere with the normal arming/firing sequence.

(b)(3)

The Division of Military Application, in forwarding the development request, suggested that the program be assigned to the Lawrence Radiation Laboratory.[7]

(b)(1), (b)(3)

If this test proved successful, weaponization would be completed in about another 2 years. It was felt that sufficient confidence in the design might be generated to warrant its stockpiling without full-scale detonation.

(b)(1), (b)(3)

Lawrence Radiation Laboratory and Sandia-Livermore notified the Division of Military Application, October 29, 1959, that in view of the existing heavy weapon work load, it was important that the MINUTEMAN warhead be scheduled no earlier than required by missile production. The desired date appeared feasible, but its accomplishment would depend on the schedule set by the re-entry vehicle program.

(b)(1), (b)(3)

Sandia issued a development program definition for the XW-56 December 24, 1959.[11]

(b)(1), (b)(3)

The nonnuclear components of the XW-56 would weigh less than those of the XW-47, and it was felt that the gross warhead weight would be about 670 pounds. (b)(1), (b)(3)

(b)(1), (b)(3)

The 16 flight tests required would start about May 1961 and furnish structural, environmental and systems operational data. Pilot-production release was scheduled for early 1961, with complete engineering release by the middle of the year. Early production would be achieved by mid-1962.

The firing system would contain an inertial generator, X-unit and environmental sensing devices, with a ferromagnetic design as alternate. The warhead would not be structurally integrated with the re-entry vehicle, but would be supported near the warhead midpoint. This type of support would simplify the missile interface problems.

(b)(3)

The MINUTEMAN missile had a diameter of 5.5 feet, length of 58 feet, launch weight of 65,000 pounds, re-entry vehicle weight of 915 pounds, range of 2,000 to 5,500 nautical miles, maximum velocity of 24,000 feet per second, impact velocity of 600 to 800 feet per second, and a three-stage solid-fuel propulsion system. Launching facilities included a fixed underground silo complex or a mobile platform.

No new materials would be required by the program, and all weapon components were used in other projects.

(b)(1), (b)(3)

The Division of Military Application sent a teletype to Albuquerque Operations Office May 2, 1960, proposing three possibilities for warhead development.

(b)(1), (b)(3)

Sandia-Livermore was asked whether development of the modified XW-56 would delay the operational availability date of June 1962, and the Division of Military Application was informed that design was in progress and that the date would be met.[15]

By May 1960 a decision was made to use a ferromagnetic transducer in the XW-56 system. It would be necessary to include diodes in the arming and surface-burst fire lines for isolation. Due to current requirements, silicon rectifier diodes appeared to be the only practical type, and development was under way on an arming-line diode that could handle surge currents and have sufficient resistance to radiation.[16]

A decision had been made to use fuse-actuated switches. Four of these would be mounted on a printed circuit board and packaged in a switch pack, with two switches protecting exciting-current input lines to the ferromagnetic transducer and two others protecting fire-signal input lines. Closure of the switches in the current input lines would provide one of the two required independent arming signals.[17]

(b)(1), (b)(3)

(b)(1), (b)(3)

Field Command noted that there was no apparent advantage to a mixed arsenal of tested and untested warheads, as the best design should be selected. The Radiation Laboratory saw some benefit in a mix of lower-weight, lower-yield tested warheads for the XW-56 until the XW-56-X1 design became available, as the reduced weight would extend the range of the MINUTEMAN to more targets.

At the request of the Division of Military Application, the Radiation Laboratory provided additional information August 25, 1960.

(b)(1), (b)(3)

(b)(1), (b)(3)

Field Command, in a teletype to Sandia September 7, 1960, noted that it would be at least theoretically possible to design a weapon containing a Los Alamos primary and a Radiation Laboratory secondary.

(b)(1), (b)(3)

Meanwhile, Sandia had originated Report SC4819(WD), Proposed Ordnance Characteristics of the XW-56 Warhead.

(b)(1), (b)(3)

The report stated that early mechanical interface designs included various forward and rear supports of the warhead. The design was changed to a single

mechanical interface flange, which provided a cantilevered support of the warhead in re-entry vehicle and avoided differential thermal expansion problems between warhead and re-entry vehicle structure.

The warhead would have an explosive ferromagnetic transducer. The system would contain dual arming and firing circuits, and environmental sensing devices would prevent inadvertent signals from activating the warhead. The system would detonate the weapon by either air-burst or contact-burst firing signals supplied by the re-entry vehicle arming and fuzing package.[23]

Field Command notified Sandia, September 23, 1960 that the ordnance characteristics report had been reviewed in coordination with representatives of the three Services. The report noted that the use of a reversible arm/safe operation solely for the purpose of receiving power and/or signals for safing appeared to be neither practical nor feasible. Additionally, in view of recent warhead design changes, no firm time interval for full arming could be established. Both these conditions were accepted, and the review established that the design met all requirements of the approved military characteristics. However, it was requested that positive means be provided to prevent transfer of boosting gas into the pit in event of external fire.[24]

The Director of Defense Research and Engineering, in a letter dated October 13, 1960, approved the 600-pound XW-56-X1 design for the MINUTEMAN warhead.[13]

(b)(1), (b)(3)

(b)(1), (b)(3)

An operational availability date of July 1, 1962 was requested for a normal-version warhead, as well as a maximum-yield 600-pound warhead with an availability date of July 1963.

(b)(1), (b)(3)

This latter design would have the maximum yield possible without nuclear test and would be compatible with advanced design re-entry vehicles.

(b)(1), (b)(3)

The XW-56-X1 would be called, in production, the Mk 56 Mod 1 Warhead.[28]

Lawrence Radiation Laboratory and Sandia-Livermore forwarded the development program definition of the XW-56-X1 to Albuquerque Operations Office March 24, 1961. A series of 10 warhead flight tests would start by July 1962. Engineering release was planned for mid-1962 and early production for May 1963.

(b)(1), (b)(3)

(b)(1), (b)(3)

Environmental safing devices would provide warhead safety before the warhead was mated to the arming/fuzing package. The warhead would be sealed. A single flange would be provided for attachment to the re-entry vehicle structure.

(b)(1), (b)(3)

No materials or components were expected to present any unusual procurement or manufacturing problems.[29]

In June 1961 the Division of Military Application requested operational availability by April 1963, and it was agreed that, with increased effort, this date could be met.[30] In September 1961 Albuquerque Operations Office requested a first-production-unit date of February 1963 and increased quantities of warheads in the early months of production.[31] The difficulties in supporting such effort were discussed, and this additional acceleration was canceled. Production was authorized in September 1961 and the Division of Military Application subsequently notified the Military Liaison Committee that early units would be available by March 1963.[32]

(b)(1), (b)(3)

The design was accordingly

changed, January 18, 1962, to use external initiators and a chopper-converter firing set.[33] The XW-56-X1 was redesignated XW-56-X2, but retained production nomenclature of Mk 56 Mod 1.[34]

(b)(1), (b)(3)

The Mk 56 Mod 1 Warhead was design-released in May 1962.

(b)(1), (b)(3)

The report was accepted by the Design Review and Acceptance Group December 18, 1962.[37]

Previously, Sandia-Livermore had notified Albuquerque Operations Office that a reasonable degree of radiation hardening could be accomplished with little effect on the yield, weight and operational availability date. Existing hardening methods would, however, impose limitations on low-temperature, long-term storage, and techniques to avoid this limitation were under study.

(b)(1), (b)(3)

Sandia-Livermore sent a teletype to the Division of Military Application December 20, 1962, noting that efforts had been made to increase the resistance of the warhead to blast effects produced by antimissile defense systems and stating that the method of mating warhead to re-entry vehicle would be changed. Instead of a single-flange cantilevered mounting system, paper honeycomb would be placed between warhead and re-entry vehicle to provide area loading.

This design change would be called the XW-56-X3 and would become, in production, the Mk 56 Mod 2. The design-release date would be July 1963.[40]

(b)(1), (b)(3)

The Mk 56 Mod 2 would not be interchangeable with Mk 56 Mod 1, and early production was scheduled for April 1964.[41]

Report SC4868(WD), Mk 56 Mod 1 Warhead Final Development Report, was issued March 1963. This noted that early production had been accomplished. The Mk 56 Mod 1 Warhead was 17.4 inches in principal diameter, 47.3 inches long, weighed 600 pounds, and was compatible with the Mk 11 re-entry vehicle.

(b)(1), (b)(3)

The electrical system had two parallel arming and firing channels. Since some of the components operated irreversibly, the signals had to be given in proper

motor. The transformer secondary was connected to storage capacitor and neutron generators through a voltage regulator.

(b)(3)

The warhead could be detonated by either air-burst or surface-burst signal. The signal was produced by the arming/fuzing system and operated a puncture switch, which discharged the storage capacitors through the warhead detonators. Output from this puncture switch also actuated the neutron generators, assuring an ample supply of neutrons at nuclear detonation time.[42]

(b)(1), (b)(3)

(b)(1), (b)(3)

Report SC4869(WD), XW-56-X3 Warhead Preliminary Development Report, was issued October 1963. This noted that the warhead would be used with the Air Force's Mk 11A re-entry vehicle system, and would provide interim hardening against blast effects. Early production was scheduled for April 1964 and the warhead would be called the Mk 56 Mod 2.

The XW-56-X3 Warhead, was 32 inches in maximum diameter, 80.5 inches long, and weighed 831 pounds.

(b)(1), (b)(3)

With minor exceptions, the warhead electrical system was unchanged. Inertial switches were redesigned, as early designs could not withstand high loads. These inertial switches were incorporated in the firing set and the firing set redesignated. The neutron generator was also redesignated, due to a change in mounting. Design release was accomplished in July 1963.[46] The report was presented to and accepted by the Design Review and Acceptance Group, and forwarded to the Division of Military Application October 31, 1963.[47]

Sandia-Livermore, in a letter dated May 20, 1966, noted that a program to harden the Mk 56 Mod 2/Mk 11A against hot (high energy) X-rays had been proposed by the Ballistic Systems Division of the Air Force Systems Command.

(b)(1), (b)(3)

The Division of Military Application, May 5, 1966, requested that the nuclear laboratories provide design support for the X-ray hardening program, and an analysis was completed and forwarded June 28, 1966.

(b)(1), (b)(3)

The forward shield that interfaced with Sandia components and the nuclear package would be designed by Sandia-Livermore. Sandia was planning design release by October 1966, with deliveries of production weapons by March 1967. The design would be called the XW-56-X4, with production nomenclature of Mk 56 Mod 3. Existing Mk 56 Mod 2 Warheads would be retrofitted with the new design.[53] Subsequently, however, delays were encountered in missile deliveries, and the design release was deferred to December 1966 and early production to February 1967.[54]

(b)(1), (b)(3)

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2.0 Description of the B57 Bomb

The B57 is a single stage, lightweight, multipurpose bomb designed for use as a depth bomb, or in tactical and strategic weapon applications.

[redacted]

DOE (b)(3)

The B57 is currently fielded in two basic Mods, Mod-1 and Mod-2, which are essentially identical except Mod-2 incorporates a Category B PAL. Either Mod can be configured with any one of three field-interchangeable noses. The N57-0 Ballistic Nose, N57-1 Radar Nose or N57-2. The N57-2 is an improved high friction impact nose designed to remove the low level delivery restriction on the bomb with the Mod-0 Nose. The B57 may be deployed in either depth bomb or Laydown with any of the three noses; however, it must have the N57-1 Radar Nose for the Airburst options.

2.1 Nuclear System - Description

[redacted]

DOE (b)(3)

DOE (b)(3)

2. High Explosive

Composition	Quantity (lbs)
PBX -9011	[redacted]
PBX - 9404	
Total	

DOE (b)(3)

[redacted] UNCLASSIFIED

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3. The Pit is a Type 104.

[redacted]

DOE (b)(3)

B. Reservoirs.

[redacted]

DOE (b)(3)

The following definitions apply:

Cycle Life - The interval from fill time to the time that the gas no longer meets the weapon yield certification because of tritium decay.

[redacted]

DOE (b)(3)

Extended Cycle Life - The interval from fill time to the time that "unacceptable" yield degradation results from tritium decay and helium generation. This time is greater than the cycle life and less than or equal to the limit life.

Limit Life - The interval from fill time to the time that the structural integrity of the reservoir, including an appropriate factor of safety, may be compromised, resulting in an increased probability of a tritium leak.

UNCLASSIFIED

DOE
b(3)

[redacted]

UNCLASSIFIED

[redacted]

DOE (1)

Alt 284 added a stronger clevis and lug to allow carriage of the B57 on "High Performance " aircraft and removed a MAR restriction which limited the side load on the forward lug to a maximum of 1000 pounds.

[redacted]

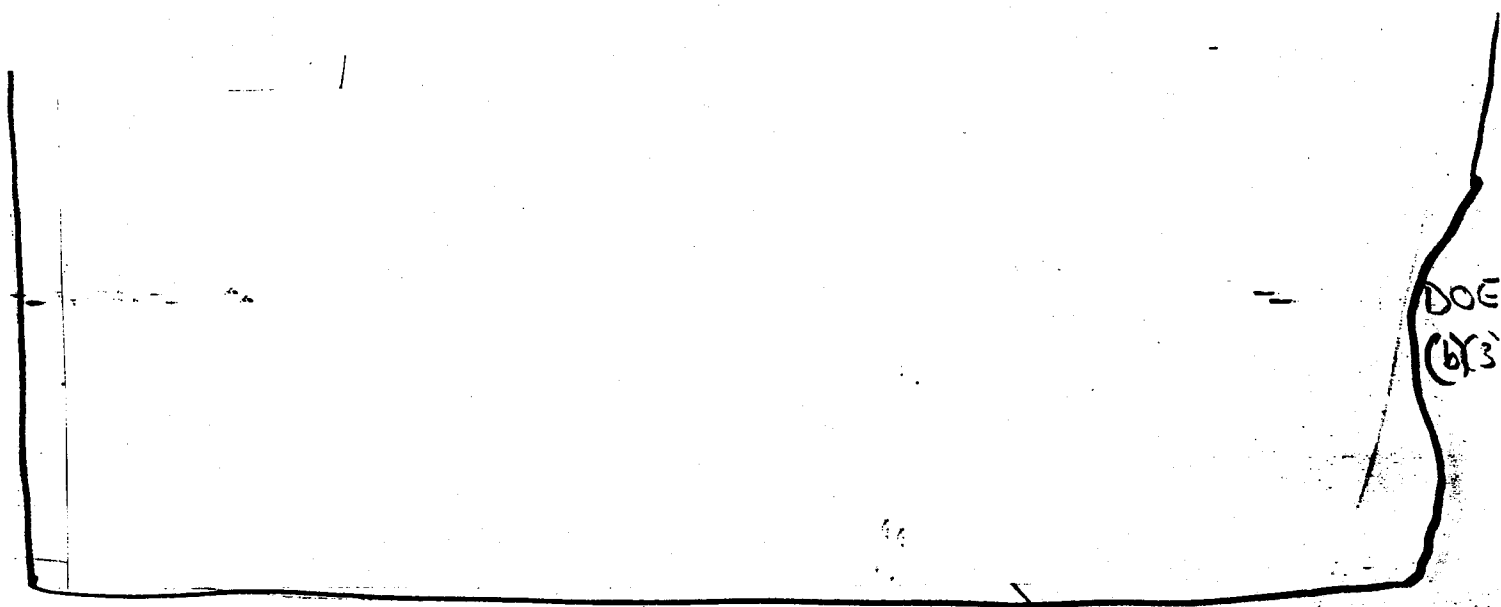
DOD b(1) 1.6(a):X4

Alt 728 incorporates a thermal battery power supply in the N57-1 Nose. Alt 0 noses have a turbo-generator power supply. (No reported age related problem with this propellant.)

[redacted]

DOE (b)(3)

DOE b(3)


DOE
(b)(3)

4. [redacted] DOE 6(3)

2.5.2 Current authorized STS is FC/10610257, RS 3446/1964, published 31 October 1961

Several revisions to this basic document have been proposed but none have been accepted due to the extensive test program that would have to be initiated to verify the requested changes in requirements that were proposed.

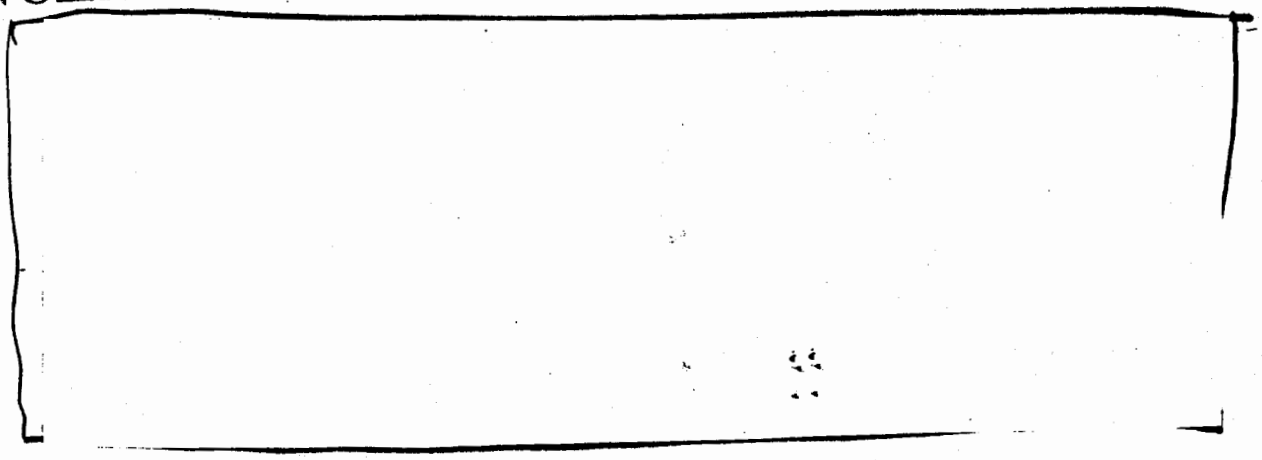
3.0 Description of Positive Measures

The B57 pre-dates Enhanced Nuclear Detonation Safety (ENDS) design methodology and components, Fire Resistant Pit (FRP) designs and the development of Insensitive High Explosive(IHE). It also pre-dates the development and definition of Nuclear Safety Rules. Following paragraphs identify design features that provide some assurance against the requirements of each of the Nuclear Safety Rules.

3.1 "There shall be positive measures to prevent nuclear explosives involved in accidents or incidents from producing a nuclear yield."

[redacted] DOE 6(3)

[redacted] DOE (6)(3)



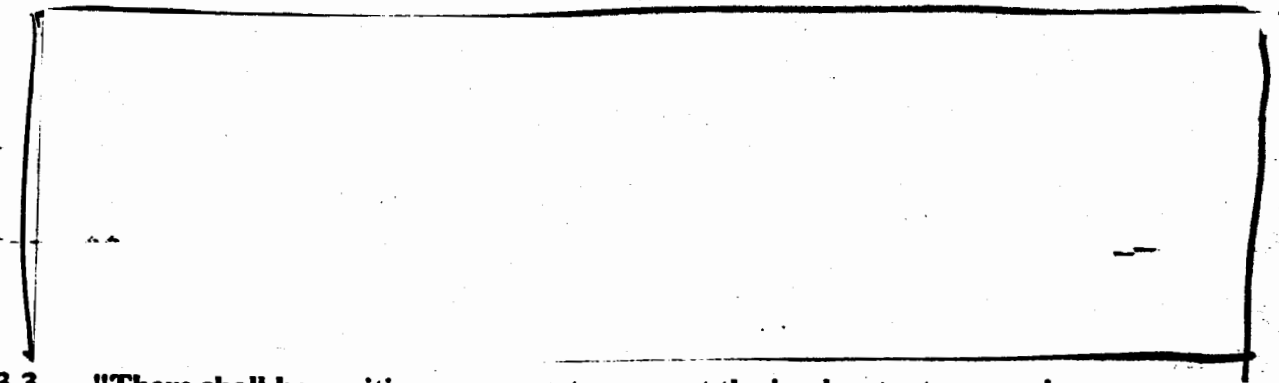
3.1.1 During carriage on a strike aircraft (accident or jettison):

1. The Ready/Safe switch should be in the "SAFE" position.
2. There should be no power on the pull-out cable, required to start the prearm sequence.

3.1.2 During a logistic movement operation (accident or incident):

1. The Ready/Safe Switch will be in the "SAFE" position, isolating internal power.
2. The Strike Enable Plug should be absent (isolating internal battery power).
3. There are no lanyard connections to either the pulse plug or the pull-out switch, both of which must function to initiate prearming.
4. Neither of the trajectory sensing systems will normally experience the environment required to operate the trajectory switch, thereby precluding further arming of the bomb.

3.2 "There shall be positive measures to prevent deliberate prearming, arming or firing of a nuclear explosive except when directed by competent authority."



3.3 "There shall be positive measures to prevent the inadvertent prearming, arming, launching, firing or releasing of a nuclear explosive in all normal and credible abnormal environment."

The required sequence of events under normal environments would act to preclude inadvertent prearm, arm or release.

[redacted]

DOE (b)(3)

3.4 "There shall be positive measures to ensure adequate security of nuclear explosives pursuant to the DOE safeguards and security requirements."

Security is handled by systems external to the weapon system. Such factors as fences, guards, two person control and Personnel Assurance Program (PAP) are examples of DOE (and DoD) security measures.

3.5 "There shall be positive measures to prevent accidental, inadvertent, or deliberate unauthorized dispersal of plutonium to the environment."

There are *no* **positive** measures; the B57 has conventional high explosive.

4.0 Summary of Past Safety Studies and Investigations

4.1 DOE and Laboratory Internal Studies

The B57 bomb is a weapon designed prior to the incorporation of the modern safety concepts of isolation, inoperability and incompatibility. The weapon does not utilize Enhanced Nuclear Detonation Safety (ENDS) nor does it have IHE or FRP.

[redacted]

DOE (b)(3)

4.1.1 Retrograde Surety

A study was conducted for the Executive Management Team for Dismantlement to identify options for enhancing Surety during the dismantlement process. In

recognition of system deficiencies, as detailed in paragraph 3 above, we have identified options to address these shortcomings. A tabulation of these options and the relative improvements to nuclear detonation safety and plutonium scatter is shown in the following table. Additional comments on each option are provided below:

Option 1. [redacted]

Option 2. [redacted]

DOE (b)(3)

Option 3. Use of the Transportation Accident Resistant Container (TARC), in the B57 application, requires disassembly of the bomb and shipment of only the separate Center Bomb Subassembly in the container. Work is moving apace in the development, testing and fabrication of this configuration.

Option 4. Restricting shipment of B57 bombs to the SST is the recommended option.

4.2 TWG Reports. In 1975-76 there was a joint ERDA(DOE)/DoD effort to characterize "older weapons" in abnormal environments and combinations of these abnormal environments. The reports generated by these studies are referred to as "TWG Studies" (Technical, Working Group). The findings of these working groups are common across the services; only the individual accident scenarios differ..

- In mechanical abnormal environments, Impact, Crush, Immersion, Puncture, Acceleration, Blast, and Vibration, B57 response is completely predictable only in Immersion, Acceleration and Vibration environments.
- In Electrical abnormal environments, External Power Sources, Static Charge, EMR, and Lightning, the B57 response is completely predictable only in Static Charge and EMR environments.
- In Thermal environments the response of the B57 is predictable below 500°C or beyond the temperature at which the HE ignites. The possibility of Pu scatter as one result of HE ignition was not considered by the TWG.
- The B57 response to Chemical environment is predictable.

See Appendix B for additional details

4.3 Recent NWSSG Studies

4.3.1 Reports

Ref. 1. SRD Report, 3/26/92, RS3145A/92/00823; NWSSG 92-1, NWSSG 1087, Report of the Special Safety Study of the H1501 Series Shipping Containers with the B57 Bomb (U).

Observes that the B57 does not meet Modern Nuclear Safety Criteria and is nuclear safety enhancement.

Ref. 2. SRD Report, 5/92, RS3913-2/92/00401; NWSSG 92-2, Report of the Special Safety Study of the Product Change Proposal 2-92 of Alt 914 for the B57 Bomb.

Observes that incorporation of Alt 914 in the B57 bomb does not alter the non-conformance with the first and third DOE safety Standards of weapon system employing the B57 bomb.

Ref. 3. RD Report, 3/91, RS3141/91/1154; Special Safety Study of Navy B57-1,-2 and B61-0,-2 Older Nuclear Weapons Systems (April 1991).

Observes that older weapons are unable to satisfy the four DOE Safety Standards and should be prohibited from Nuclear Exercises (Readiness). A Minority report countered the last comment.

Ref. 4. SRD Report, Sept. 1991, RS 3145A/91/03064; NWSSGR 91-6, Nuclear Weapon System Safety Group Report of Operational Safety Review of the P-3C Aircraft with the B57 Bomb (U).

Ref. 5. [redacted] DOD b(1)

4.3.2 Safety Rules, Air Force Nuclear Weapon Systems

Ref. 1. AFR 122-26, Safety Rules for the US F-16A/B/C/D Weapon System, October 1988
Ref. 2. AFR 122-27, Safety Rules for the Non-US NATO F-16A/B/C/D Weapon System, December 1998.
Ref. 3. AFR 122-37, Safety Rules for the F-111A Weapon System, July 1990
Ref. 4. AFR 122-47, Safety Rules for the FB-111A Weapon System, July 1990

4.3.3 Safety Rules Navy Systems. (TBD)

4.4 Last NESS. Pantex in Oct. '88

4.4.1 Specific Nuclear Safety Rules, Pantex Facility
Ref. AL5610.11, Chapter XII

Article 13. Specific Safety Rules for the B57 Bomb

a. Upon bomb return and before disassembly operations are performed, an electrical continuity test shall be made to verify that the Ready/Safe switch is in the SAFE position and that the inertial switches and the switches in the explosive switch pack (located in the fuzing component assembly) are in the unactuated position.

b. When installed on the nuclear explosive, the Ready Safe Switch shall be maintained in the SAFE position.

c. The Strike Enabling Plug shall not be installed on the nuclear explosive and shall be controlled in a manner to preclude unauthorized use.

d. When installed on the nuclear explosive, the pullout switch shall be maintained in the unactuated position.

e. When the interconnecting box (located in the preflight selection bomb subassembly) is on the nuclear explosive, the J1 telemetry connector shall have the specified electrical connector cover installed.

5.0 Summary of Known Safety or Security Issues While in DoD Custody

5.1 Safety

Items of concern are discussed elsewhere (Section 6).

5.2 Security

[redacted]

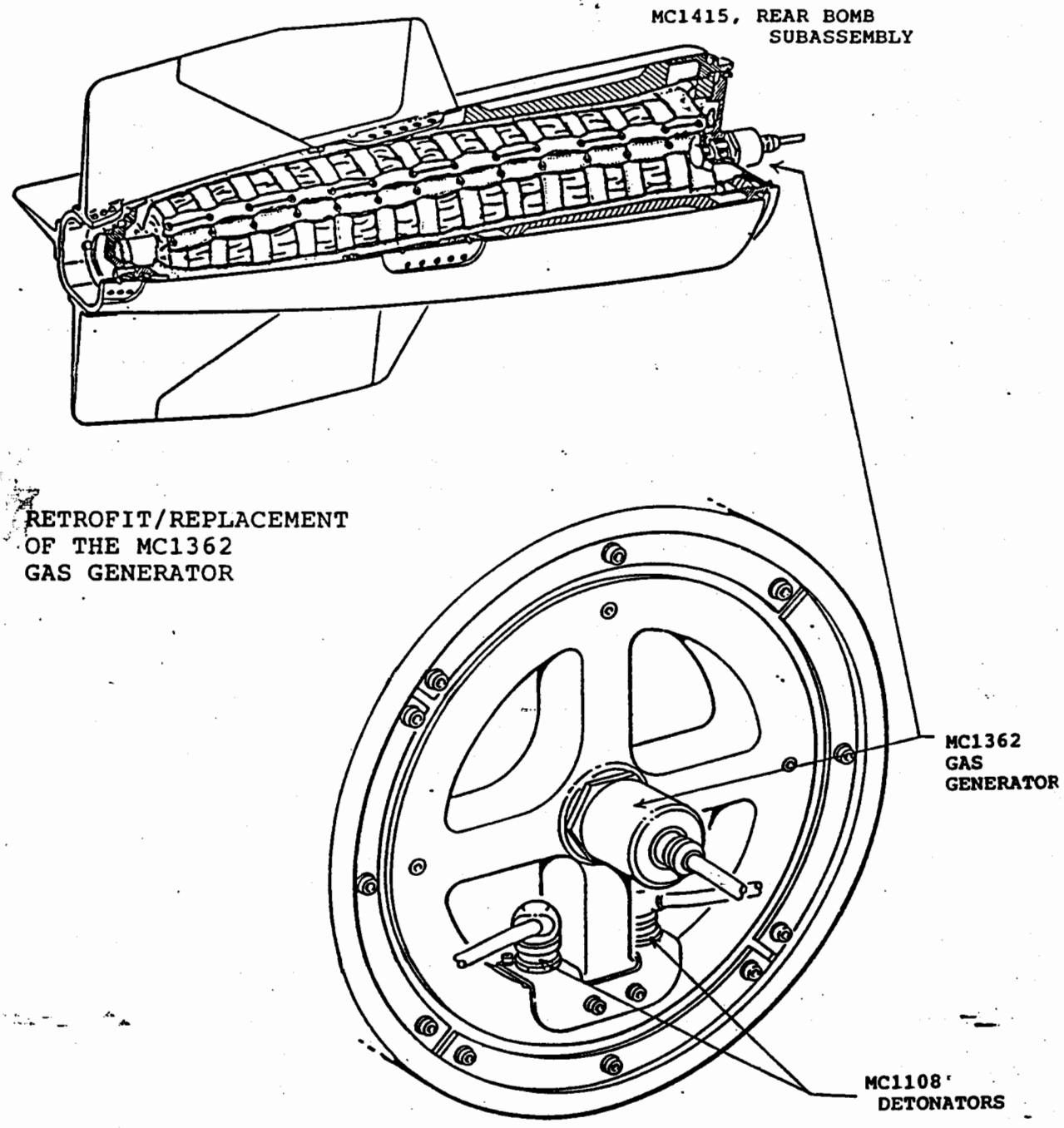
DOD
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DOE
(b)(3)

5.3 Use Control

[redacted]

DOE
(b)(3)


MC1415, REAR BOMB SUBASSEMBLY
RETROFIT/REPLACEMENT OF THE MC1362 GAS GENERATOR
MC1362 GAS GENERATOR
MC1108 DETONATORS

7.0 Findings and Recommendations

7.1 General

Although the B57 bomb meets the Military Characteristics and Stockpile-to-Target Sequence specified, it does not incorporate enhanced nuclear detonation safety design features and predates the development of insensitive high explosives(IHE) and plutonium scattering safety features. Thus, there is no assured level of safety in a broad range of abnormal environments such as could be encountered during alert, force generation exercises, and air transport.

The following issues prevail:

- The MC1362 Gas Generator propellant is approaching the limit of assured safety. The threat, the failure mechanism, is possible auto ignition, presenting a personnel / facility hazard.

DOE (b)3

DoD b(1)

7.2 Recommendations

DOE (b)(3)

- As a DOE position, the use of SSTs is the only proven safe, secure means of transporting the B57.
- Air transportation should be considered only if other factors eliminate the use of SSTs. If air transportation is necessary, both the use of TARCs (H1501 or H1501A) and the employment of Alt 914 should be required. Alt 914 improves the nuclear detonation safety, with or without the use of the TARC, two to three orders of magnitude. The use of TARC will improve Pu scatter probability by an order of magnitude.

Appendix B

ERDA(DOE)/DoD TECHNICAL WORKING GROUP (TWG) STUDIES OF 1976

During the TWG studies no attempt was made to quantify anticipated responses to abnormal environments, or combinations of environments as represented by accident scenarios studied. Rather, anticipated responses to these environments were characterized as one of three predefined conditions:

PREDICTABLE	A predictable response is one in which a critical component, subsystem or system can be depended upon with a high degree of confidence to respond in a manner that is known and safe.
UNPREDICTABLE	An unpredictable response is one in which a component, subsystem or system responds in a manner that is not always repeatable and may contribute to the weapon being unsafe.
UNDESIRABLE	An undesirable response of a critical component or subsystem in one in which it is expected to respond in a manner that contributes to a weapon being less safe. An undesirable response for a system is one in which it is expected to respond in a manner that is unsafe.

Note that the single concern was nuclear contribution to an accidental detonation. Plutonium scatter was not a concern during this era. Hence an assured HE detonation which will have no nuclear contribution was termed "Predictable".

B57 response to the various abnormal environments individually is common to both Air Force and Navy TWGs and are summarized in Table 1.

B57 responses to Air Forces Accident Scenarios is presented as Table 2. Navy responses are presented in Table 3.. The effects of performing Alt 914 on anticipated Navy accident scenarios responses is presented as Table 4.

Table 1. B57 Response To Abnormal Environments
TWG Summary

Air Force Studies

1. Air Force/ERDA - Joint Nuclear Stockpile Safety Evaluation of USAFE/PACAF Aircraft Weapon Systems Report, dated 9 August 1976
2. Air Force/ERDA - Joint Nuclear Stockpile Safety Evaluation of Non-NATO Aircraft Weapon Systems Report, dated 7 July 1976

Air Force Accident Scenarios envisioned by the Task Group and the B57 responses are summarized in Table 2.

Table 2. B57 Responses To Air Force Accident Scenarios

Navy Studies

Joint Navy/ERDA Nuclear Safety Evaluation of Navy Attack Aircraft Weapon Systems: NWEF Reports (1) 11316, dated March 1976, (2) 1136, dated June 1976, and (3) 1136-1 Executive Summary, dated June 1976. A summary of the accident scenarios envisioned and the B57 responses are presented as Table 3.

Table 3. B57 Responses to Navy Accident Scenarios

UNCLASSIFIED

Appendix C

References, in the order mentioned in the text of this report:

1. MAR 1-74, Effective date 28 May, 1974

2. STS, FC/10610257, RS 3446/1964, Published 31 October, 1961

3. DOE Order AL5610.10, dated 10/10/90

4. SECRET RD/CNWDI Report, Nuclear Weapons Council Report on the Special Stockpile Improvement Plan Review, (SSIPR), dated January 1992., NWCWSC Comment Draft, RS3145A/92/00324.

5. SECRET/CNWDI Report, RS3141NC/503186, Air Force/ERDA -Technical Working Group, Subgroup Report, Joint Stockpile Nuclear Safety Evaluation of USAFE/PACAF Aircraft Weapon Systems, dated 9 August 1976

6. SECRET/CNWDI Report, RS3141NC/503097, Air Force/ERDA -Technical Working Group, Subgroup Report, Joint Stockpile Nuclear Safety Evaluation of NON US-NATO Aircraft Weapon Systems, dated 7 July 1976

7. SECRET/CNWDI Report, RS 3141NC/502974; NWEF Report 1131, dated. March 1976, Subject: Navy/ERDA Technical Working Group, Subgroup Report. Joint NAVY/ERDA Nuclear Safety Evaluation of Air launched Antisubmarine Warfare (ASW) Weapon Systems (B57/P-3A, B & C; S-3A: SH-3A,D,G&H)

8. SECRET/CNWDI Report, RS 3141NC/502974; NWEF Report 1131-1, dated. March 1976, Subject: Navy/ERDA Technical Working Group, Executive Summary, Joint NAVY/ERDA Nuclear Safety Evaluation of Air Launched Antisubmarine Warfare (ASW) Weapon Systems (B57/P-3A, B & C; S-3A: SH-3A,D,G&H)

9. SECRET/CNWDI Report, RS 3141NC/502976; NWEF Report 1131-2, dated. March 1976, Subject: Navy/ERDA Findings of The Navy/ERDA Nuclear Weapons Safety Study Group, Addendum to Joint NAVY/ERDA Nuclear Safety Evaluation of Air Launched Antisubmarine Warfare (ASW) Weapon Systems (B57/P-3A, B & C; S-3A: SH-3A,D,G&H)

10. SRD Report, RS3145A/92/00823; NWSSG 92-1, NWSSG 1087, Report of the Special Safety Study of the H1501 Series Shipping Containers with the B57 Bomb (U), dated 3/26/92

11. SRD Report, RS 3913-2/92/00401; NWSSG 92-2, Report of the Special Safety Study of the Product Change Proposal 2-92 of Alt 914 for the B57 Bomb, dated 5/92

12. SRD Report, RS3141/91/1154; Special Safety Study of Navy B57-1,-2 and B61-0, -2 Older Nuclear Weapons Systems (April 1991), dated 3/91

13. SRD Report, RS 3145A/91/03064; NWSSGR 91-6, Nuclear Weapon System Safety Group Report of Operational Safety Review of the P-3C Aircraft with the B57 Bomb (U), dated Sept. 1991

14. [redacted]

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b(1)

15. AFR 122-26, Safety Rules for the US F-16A/B/C/D Weapon System, October 1988

16. AFR 122-27, Safety Rules for the Non-US NATO F-16A/B/C/D Weapon System, December 1998

17. AFR 122-37, Safety Rules for the F-111A Weapon System, July 1990

18. AFR 122-47, Safety Rules for the FB-111A Weapon System, July 1990

19. DOE Order AL5610.11, Chapter XII, Article 13, Specific Safety Rules for the B57 Bomb

20. Uncl. Memo, Lawrence M. Ford, 9522, to James O. Harrison, 5115, dated August 10, 1992, Subject: Security Issues Concerning the B57 and W69

B57SPEC.DOC

UNCLASSIFIED

RS5115/92/00016, Series DR8, 35 Pages, SRD, 20 Copies, 9/21/92
Subject: B57 Special Study Report (U)

Distribution:

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February 1968

RS 3434/39
AEC ATOMIC WEAPON DATA
Sigma 1

Changed to Sigma 1 by authority of Notice 3414 NA(1315), 6/27/68. File No. 3588, 7/2/68. Manager, Nevada.

HISTORY OF THE MK 58 WARHEAD (U)

SC-M-68-50

SC-M-68-50 39
~~SECRET~~
02/68

Weapon Systems

Redacted Version

Information Research Division, 3434

Classified By: Richard B. Craner
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Timetable of Mk 58 Events

Mid-1959	Development of concern over enemy defenses to ballistic missile attacks. Cluster warheads proposed.
8/59	Study of cluster warheads completed, and design recommended.
11/24/59	Director of Defense Research and Engineering requests Atomic Energy Commission to participate in feasibility study of a cluster warhead for the POLARIS missile.
1/22/60	Feasibility study report recommends development of thermonuclear cluster warhead for POLARIS.
7/60	Decision made that both air-burst and surface-burst fuzing be provided.
7/19/60	Director of Defense Research and Engineering requests United States Atomic Energy Commission to design POLARIS warhead. Nuclear portion of project assigned to Lawrence Radiation Laboratory.
8/16/60	Military characteristics for POLARIS warhead approved by Military Liaison Committee.
10/60	Nomenclature of XW-58 assigned to warhead.
1/25/61	Sandia and Lawrence Radiation Laboratory forward development program definition of XW-58 Warhead to Albuquerque Operations Office.
8/8/61	Report SC4830(WD), XW-58 Warhead Proposed Ordnance Characteristics, reviewed by Navy and accepted.

(b)(1), (b)(3)

11/6/62	Mk 58 Warhead program authorized for production.
5/16/63	Mk 58 Mod 0 Warhead design released.

(b)(1), (b)(3)

Preliminary design suggested that the three re-entry bodies be mounted on a support structure and an ejection system be provided to disperse the rocket-propelled re-entry bodies at an altitude of about 200,000 feet on the exit phase of the missile trajectory. An ejectable fairing would cover the three re-entry bodies during underwater launch of the POLARIS A-3 missile and throughout early flight phase.

(b)(3)

Two basic configurations were being considered for the re-entry bodies. Both had the same cylinder and flare, but differed in nose shape. A hemispherical nose shape would be made of pyrolytic graphite material, and an elliptical nose shape would be made of either pyrolytic graphite or beryllium. Either design would result in a maximum inner wall temperature of 1500°F, and insulation between the inner wall and the warhead would limit the temperature of the latter to not more than 300°F.[7] The hemispherical shape was eventually chosen.

By July 1960 a decision had been made that both air-burst and surface burst fuzing would be provided. (b)(3) The air-burst fuze would be an inertial type consisting of a range-corrected timer started by decelerometer. The air-burst fuze would be effective against about 95 percent of the targets proposed for the POLARIS weapon system. The remaining 5 percent would be located at too high an altitude, and would be attacked with the surface-burst fuze. A means would be provided for selecting surface burst for any target.

The primary safety component was the decelerometer. This would be an integrating type requiring a deceleration of 10 g's for 5 seconds before permitting arming. An integrating accelerometer would function as a complementary safety device for added safety during handling and to isolate electrical circuits entering the re-entry body. An interlock assembly and a pulse-type pullaway connector would prevent arming in the event the missile was off course or re-entry body/missile separation was not achieved. A thermal battery initiated by re-entry heat would supply power.[8]

The Director of Defense Research and Engineering, in a letter dated July 19, 1960, requested the United States Atomic Energy Commission to proceed with design of the POLARIS Warhead.[9]

(b)(1), (b)(3)

It was noted that the Lawrence work load was quite heavy, and that no new development programs should be assigned to this laboratory in fiscal 1961 without compensatory reduction in other programs. However, since the operational availability date of the POLARIS Warhead called for a 4-year development cycle, rather than the 3 years specified in the warhead feasibility study, it was felt that adjustments to other weapons programs might not have to be made.[10]

The military characteristics for a POLARIS Warhead were approved by the Military Liaison Committee August 16, 1960. Three similar warheads would be used in each missile assembly.

(b)(1), (b)(3)

The Department of Defense was responsible for the weapon, exclusive of the warhead, and had designated the Bureau of Naval Weapons as the cognizant agency for development of the POLARIS system. The Lockheed Missile and Space Division was missile system manager and was responsible for re-entry body system, missile assembly, support equipment, and testing. The Naval Ordnance Laboratory would provide an integrated fuzing and firing system.

The flight-test program would encompass 14 tests, which would start in October 1962. Pilot release was being planned for December 1962 with complete design release by March 1963. Early production had been accelerated to January 1964 and operational availability with a POLARIS submarine complement of 48 warheads by June 1964.

(b)(1), (b)(3)

The integrated fuzing and firing system would be a Military responsibility and would provide air-burst fuzing, controlled by a barometric switch, having three burst-height options and surface burst. Environmental sensing devices would prevent system operation until all environments associated with a normal launch and re-entry trajectory had been experienced.

The firing system would contain an explosive-electric transducer, and the warhead would be sealed, either as an entity or as an integral part of the warhead/nose-cone assembly. The boosting-gas reservoir would be installed in a well and would allow replacement without breaking the warhead seal. The warhead would be attached to the re-entry system structure by a flange near the aft end of the warhead.

The POLARIS A-3 missile had a maximum diameter of 54 inches, length of 31 feet, launch weight of 35,000 pounds, and a range from 500 to 2500 nautical miles. The missile

in coordination with Navy representatives. The review established that the design met all requirements of the approved military characteristics and all other known operational, logistic and safety requirements of the Department of Defense. The design was acceptable to the Military.[18]

(b)(1), (b)(3)

Measures were being taken to limit the effects of countermeasures on the warhead.

The individual re-entry bodies were being designed with a maximum flare diameter of 23.5 inches, length of 54 inches, and weight of 300 pounds. Each contained a nuclear system and an integrated fuzing and firing system, surrounded by an outer heat shield. This heat shield had been changed in September 1961 from a pyrolytic graphite design to an ablative heat shield integral with the warhead structure.[19]

(b)(1), (b)(3)

This redesign resulted in a delay in laboratory and flight tests, and caused the design-release date to slip about 3 months. The early production date of January 1964 was not expected to be affected.[21]

The Director of Defense Research and Engineering notified the United States Atomic Energy Commission February 20, 1963, that the Navy was considering a high-yield, semihardened warhead for POLARIS, and a feasibility study was requested.[28] The Division of Military Application subsequently noted that since the warhead characteristics were similar to those of the warhead being developed for the MINUTEMAN missile, the program should be assigned to Los Alamos.[29]

The Mk 58 Mod 0 Warhead was design released May 16, 1963, with the exception of re-entry body shell assembly, cover and primary. System release was completed by July 1963.[30,31]

Field Command notified Sandia-Livermore June 27, 1963 that Report SC4860(WD), Mk 58 Mod 0 Interim Development Report, had been reviewed by the Navy. The design met most requirements of the approved military characteristics. Insufficient data were available to make an evaluation of the capability of the explosive actuator to meet vulnerability requirements. Otherwise, the design met the known operational, logistic and safety requirements of the Department of Defense, but Sandia was requested to ensure that the actuator satisfied vulnerability requirements.[32,33]

(b)(1), (b)(3)

Report SCL-WD-64-18, Mk 58 Mod 1 Warhead Final Development Report, was accepted by Field Command September 2, 1964.

(b)(1), (b)(3)

Air-burst fuzing was

provided, with choice of three heights, as well as an electronic surface-burst fuze that could be used either as primary option or as backup.

The POLARIS missile had a maximum diameter of 54 inches, length of 32.32 feet, launch weight of 35,000 pounds, and a range from 500 to 2500 nautical miles. The missile was a two-stage solid-propellant rocket, with a spin-separation rocket on each re-entry body, and could be launched from either submerged or surfaced submarines. One of three height-of-burst options (timer fire) or a surface-burst option (proximity fuze) could be selected before launch and stored in the missile programmer. At launch an accelerometer enabled the warhead circuits.

Underwater launches could be made at depths up to 100 feet. The missile was ejected from the launch tube by either compressed air or a solid-propellant/steam-launch system. After the missile emerged from the water, the first stage was ignited. First-stage acceleration caused an accelerometer to operate, closing contacts which connected warhead circuitry to thermal battery and missile programmer. This accelerometer operation occurred about 55 seconds after launch, at an altitude of about 62,000 feet.

(b)(1), (b)(3)

The Bureau of Naval Weapons notified Sandia-Livermore, October 7, 1964, that POLARIS missiles were now on station, aboard the nuclear-powered submarine USS Daniel Webster. This significant milestone of a truly global deterrent was hailed as a source of pride to everyone, military and civilian, who had taken part in the nationwide POLARIS team. A heartiest "well-done" was extended to the entire POLARIS group.[38]

A report entitled "Mk 58 Mod 1 Weapon Description" was issued in December 1965. The warhead was defined as a major assembly consisting of nuclear system and electrical circuitry, hardware to hold the parts together, DOD-supplied fuzing and firing device, and DOD-supplied ablative material bonded to the warhead case.

(b)(1), (b)(3)

The entire warhead was enclosed in a magnesium case and an aluminum cover. The warhead ablative heat shield was of nylon phenolic laminate bonded to the magnesium case. The cover incorporated two antenna connectors for the target-detecting device, a baro port which provided atmospheric-pressure information to the baroswitch, and a purging port used in filling the warhead with dry air.

(b)(1), (b)(3)

A single-channel fuzing and firing device was mounted in the warhead compartment. Battery and target-detecting-device antennas were mounted in the re-entry body flare.

Development Program Definition -- A report that describes the weapon to be designed and the steps that will be taken in its development.

Director of Defense Research and Engineering -- Handles research and development activities for the Department of Defense.

Division of Military Application -- An AEC office that functions as liaison between the Military and weapons designers and producers.

Dominic -- A full-scale test operation held in the Pacific. Series of 39 tests, April 25 to November 4, 1962. Dominic was authorized after the test ban was broken by the Soviet Union in 1961.

Environmental Sensing Device -- A device that reacts to a specific environment of the weapon, such as speed, acceleration, altitude, etc.

Field Command -- The local office of the Armed Forces Special Weapons Project (Defense Atomic Support Agency), located on Sandia Base, Albuquerque, New Mexico.

Firing System -- The electrical system of the weapon that produces and applies a high-voltage current to the detonators.

Fuzing System -- The system that arms the weapon at the appropriate time and provides a firing signal to the firing system at the selected burst height.

g -- Force equal to one unit gravity.

Gas Boosting -- The technique of increasing the yield of a nuclear device by introducing deuterium-tritium gas into the implosion process to increase fission activity.

Hardtack -- A nuclear series of 72 tests. Hardtack I was held at the Pacific Proving Grounds from April 28 to August 18, 1958. The decision to declare a moratorium on testing resulted in Hardtack II, held at the Nevada Test Site between September 12 and October 30, 1958.

Kiloton -- A means of measuring the yield of an atomic device by comparing its output with the effect of an explosion of TNT. A 1-kiloton yield is equivalent to the detonation effect of 1000 tons of high explosive.

Lawrence Radiation Laboratory -- A nuclear design organization located at Livermore, California.

Military Characteristics -- The attributes of a weapon that are desired by the Military.

Secondary -- The thermonuclear portion of a two-stage weapon.

Squib -- A device containing a small explosive charge. When detonated, the resulting gas pressure closes a switch or performs a similar action. A light, quick-acting, one-shot device.

Thermal Battery -- A battery whose electrolyte is in a solid state while inactive. To activate, heat is applied to this electrolyte, melting it and putting the battery into active output condition.

Thermonuclear -- Two-stage reaction, with a fission device exploding and starting a fusion reaction in light elements.

Tritium -- The hydrogen isotope of mass number 3.

Warhead -- A weapon carried to the target by missile.

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HISTORY OF THE TX-61 BOMB (U)

Weapon Systems

Personnel Division 11 3232

Redacted Version

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Classification Analyst, Org 4225
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HISTORY OF THE TX-61 BOMB (U)

RS 3434/42

August 1971

Personnel Division II 3232

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Timetable of TX-61 Events

(b)(3)

Mid-1962	FUFO bomb program authorized to include the full range of Air Force and Navy fighters, Navy antisubmarine warfare aircraft, and multiple carriage in bombers of the Strategic Air Command.
1/18/63	FUFO bomb named TX-61.
8/20/63	First TX-61 free-fall ballistic test held at Tonopah Test Range.

(b)(3)

5/6/65	TX-61 nuclear system dimensions increased.
12/21/66	First War Reserve B61-0 accepted by the AEC.
May 1967	Production of B61-0 stopped.
Mid-1967	Modifications made on B61-0.
1/12/68	FPU of improved system accomplished.

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HISTORY OF THE TX-61 BOMB

(b)(1), (b)(3)

This weapon would be carried by Air Force Century series and STOL (Short Take-Off and Landing) aircraft.

(b)(3)

Compatibility with B-47 and B-52 aircraft appeared possible, and the group would consider application to the B-70.[3]

(b)(1), (b)(3)

Six weapons per bomb bay would be considered for the B-52, 4 weapons carried externally on pylons on the B-58, and 6 weapons per bomb bay in the B-70.

(b)(1), (b)(3)

One basic weapon configuration was desired, with maximum capability for both Tactical Air Command and Strategic Air Command applications.[5]

(b)(3)

(b)(1), (b)(3)

Environmental criteria for the TX-61 were specified. Temperature extremes from -65 to ±160 degrees F might be experienced for indefinite periods of time. Shock environments would include 50 g vertical, 40 g transverse, or 30 g longitudinal while the bomb was being transported or stored aboard ship. The exterior surfaces of the bomb might experience a maximum temperature of +275 degrees F for about 40 minutes, but all temperature-critical components would be insulated. Parachute deployment would subject the bomb to a maximum load of 255 g along the longitudinal axis.[12]

(b)(1), (b)(3)

By March 1963 the weapon was being designed so that it could be released without aircraft power after arming.

(b)(1), (b)(3)

It was hoped that the weapon would be more rugged than the Mk 57. An integrated nose assembly would contain a radar, impact crystals, and shock mitigation.

(b)(1), (b)(3)

The heavy case enclosing the nuclear assembly fuzing and firing components was being designed for maximum strength and minimum weight.

(b)(1), (b)(3)

Components would be potted and packed in foam to provide shock resistance. The afterbody would be a sheet metal assembly and would contain a power-deployed parachute system similar to that of the TX-57.[14]

The TX-61 ballistic contour would consist of a Von Karman nose, a cylindrical center section, and a parabolic afterbody. Four fins would provide stability during the drop trajectory for the free-fall

options. The unit would be parachute-retarded for the laydown and retarded-airburst options. Sufficient retardation would be provided to permit delivery from 50 feet above target elevation.[15]

The bomb would be timer-armed in all options. The firing signal would be provided by radar in the airburst option, by piezoelectric crystals in the freefall ground-contact option, and by timer in the laydown option. A gap-fired transverter-capacitor firing set and electronic neutron generators had been designated for the warhead electrical system.

(b)(1), (b)(3)

The forward subassembly would contain a bomb radar nose and its associated power supply, impact fuzes, radome, and case section. Because of the requirement for a low-drag shape to permit the weapon to be carried at supersonic speeds, the nose assembly would be pointed, and would be tipped with metal to prevent damage from rain erosion.

The center bomb subassembly would contain any elements requiring protection during laydown deliveries. These included the nuclear system, boosting reservoir and valve, firing set, permissive action link, neutron generator, sequential timer system, ready/safe rotary switch, trajectory-arm inertial switch, interval timer, and thermal batteries.

All fuzing and firing components and some nuclear system components would be mounted in polyurethane foam to maximize packaging density and to protect against laydown shock. This foam also provided thermal insulation to hold component temperatures within operational limits during supersonic carriage.

(b)(1), (b)(3)

The velocity sensor for environment sensing during freefall differed from the ones in previous weapons in that it obtained ram air pressure through a port that was located not on the weapon skin but on a cylinder which, when projected into the air stream, lifted the port about 3/4 inch from the weapon surface to prevent skin interference with air flow.

Capability would be provided for selecting any fuzing option while the delivery aircraft was airborne, as well as a preflight capability for choosing retarded or freefall delivery. Two adjustable safe-separation times would be settable before flight, and selection between these times could be made in flight. Both high and low burst heights, as well as contact backup enable, or nonbackup for the airburst options, would be selectable before flight.

(b)(1), (b)(3)

There would be some constraints on F-111 external carriage of the Mk 57, but it was felt that these would not be too severe.

The first TX-11 freefall ballistic test was held at the Tonopah Test Range August 20, 1963.

(b)(1), (b)(3)

Separation from the aircraft was clean and the weapon was stable throughout its trajectory.[16]

(b)(1), (b)(3)

Until the F-111 aircraft became available, it would be difficult to simulate this environment exactly, but some preliminary tests would be made at the rocket-sled facility in Area 3. A portable radiant-heat chamber would be used to heat the bomb, which would then be mounted on a rocket sled. When the sled had been accelerated to the proper velocity, the weapon would be ejected upward. After a prescribed delay after ejection, a gas generator would be fired, the parachute deployed, and the unit would describe a normal trajectory and impact on a flat concrete target.[17]

(b)(1), (b)(3)

Although additional development time, tradeoffs, and

probably nuclear tests would be required to attain this end, the change would be worthwhile.

(b)(1), (b)(3)

Carriage of the bomb by RF-4C aircraft was specified.[18]

(b)(1), (b)(3)

This would entail some redesign, but it was felt possible to produce a satisfactory laydown weapon. Diameter and length of the weapon would not be changed, but the weight would be increased by about 10 pounds.[19]

At this time, compatibility of the TX-61 in the freefall option with internal carriage in the F-105 had not been demonstrated, and it was thought that the aircraft suspension system might have to undergo a major redesign. The military characteristics had been amended to eliminate contact backup in the freefall option, and a strike-enable plug was added to the fuze at Navy request.

(b)(1), (b)(3)

It had been decided that trajectory arming in the freefall option would be accomplished by angular acceleration produced by a spin rocket motor. This motor, ignited shortly after bomb release, would impart a spin of 5 revolutions per second to the weapon to prevent coupling and instability under high-Mach, high-altitude release conditions.

(b)(1), (b)(3)

[redacted]

(b)(1), (b)(3)

Sandia notified the Division of Military Application that this amendment could be attained with relatively minor changes to the weapon.[26, 27]

By late 1964 discussions were being held within Sandia concerning an apparent inconsistency in the TX-61 fuzing system.

(b)(1), (b)(3)

It was pointed out that the minimum safe-separation time presently achievable in the weapon when delivered in the freefall mode was 12 instead of the advertised 10 seconds. This inconsistency was a result of a 3-second delay provided in the freefall-trajectory arming circuit. This delay dircuit prevented operation of the trajectory arming unit until 3 seconds after weapon release. When a safe separation time of 10 seconds was desired, the device was programmed to start 1 second after weapon release. However, the system could allow an additional 2 second delay, and this would result in an overall safe separation time of 12 seconds.

A spin-rocket safety-hazard tower test was conducted January 21, 1964, and showed that the 3-second delay was required. Two approaches appeared feasible; to redesign the electrical system so that a minimum safe separation time of 10 seconds could be attained when using the freefall delivery mode, or to determine whether a minimum safe separation time of 12 seconds would be compatible with the freefall delivery maneuvers specified in the stockpile-to-target sequence.

(b)(1), (b)(3)

For a minimum flight time of 16 seconds, a minimum safe separation time of 15 seconds would have to be provided so as to allow 1 second for final bomb arming. Thus the 12-second minimum safe separation time currently provided in the freefall version was adequate for the approach and delivery conditions defined in the stockpile-to-target sequence, and no modification of the timing system or junction box was required to provide compatibility with the 3-second trajectory arming delay and the minimum safe separation time of 10 seconds.[28]

The Division of Military Application notified the Albuquerque Operations Office December 24, 1964, that the first production unit date for the TX-61, in view of recent changes, would be deferred to January 1967.[29]

(b)(1), (b)(3)

A review of the development test program in late 1964 showed

that about half of the ballistic freefall and laydown tests (both sled and aircraft drops) had been completed. All these had been successful, except for a failure to stop the parachute deployment tube. Only two laydown fuzing and firing tests had been completed. The first failed due to jitter in the ready-safe switch, and the second drop missed the concrete target.

(b)(1), (b)(3)

Consideration was being given to using rocket shots or delayed parachute deployment after freefall from high altitude.[30]

Sandia notified the Division of Military Application on May 6, 1965 that some essential changes to the TX-61 nuclear system would increase the diameter of the bomb from 12.75 to 13.30 inches and the weight from 600 to700 pounds. It was felt that the established first production date could still be met.[31]

The first War Reserve TX-61-0 was accepted by the AEC October 21, 1966, which was in conformance with the scheduled production date.

(b)(1), (b)(3)

Sandia Corporation and Bendix improved manufacturing and testing procedures for the Programmer and the Air Force revised the parachute packing inspection procedures and strengthened the bag loops.

FPU of the improved system was accomplished January 12, 1968.

(b)(1), (b)(3)

The diameter is 13.3 inches, the length 141.6 inches, and the weight is about 715 pounds.

The bomb is timer-armed in all options. Firing signals are provided by radar for airburst options, by piezoelectric crystals for contact (freefall ground burst) option, and by timer for the laydown option.

(b)(3)

In all options, an escapement-regulated interval timer is used with radially or longitudinally acting acceleration switches to provide trajectory arm-

DOE (b)(3)

ing. A gap-fired transverter-capacitor firing set and an electronic neutron generator are provided to initiate weapon detonation.

(b)(1), (b)(3)

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Classified by D. N. Bray, Supervisor, B61-6,7,8/W61 Division 5111, March 3, 1989.

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Interim Development Report for the B61-6,8 Bombs (U)

Sandia National Laboratories
Albuquerque, NM, 87185
and
Los Alamos National Laboratory
Los Alamos, NM 87545

Abstract (U)

This report describes the B61-6,8 bombs in development as a part of the Stockpile Improvement Program. The bomb design, its ancillary and support equipment, and the planned test and evaluation program are presented.

Classified by D.N. Bray, Supervisor, B61-6,7,8/W61 Division 5111, March 3, 1989.

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Summary

The B61-6,8 is a factory retrofit of the B61-0,2,5, utilizing an IHE nuclear primary and enhanced electrical safety components. Use control, command disable, and improved operational flexibility features are also included. The B61-6,8 was designed to be compatible with all aircraft now approved for B61 carriage. Compatibility will only be demonstrated for those Navy aircraft listed in the MCs: A-4, A-6, A-7, F/A-18, and A-12 (when available). No known problems exist.

The B61-6,8 will be fielded to be compatible with aircraft employing AMACs without Intent Unique Signal (IUQS) generators through the employment of the MC3025 Signal Selector. The MC3025 will be removed from all bombs on or before 1 January, 2000. Only aircraft with IUQS-capable AMACs will be compatible after this time.

Significant design features of the B61-6,8 are as follows:

Physical:

Length	3597 mm (141.6 in.)
Diameter	338 mm (13.3 in.)
Weight	350 kg (770 lb)

Yields:

DOD/DOE b(3)

Delivery Options:

Freefall Airburst (FFA)
Freefall Groundburst (FFG)
Retarded Airburst (REA)
Retarded Groundburst, Laydown (REG)

Aircraft Delivery Constraints:

Certified to maximum aircraft capabilities

DOD/DOE b(3)

Safety:

Use of IHE for primary explosive
Primary is inherently one-point safe
Enhanced electrical safety to meet modern nuclear safety standards

Use Control:

DOD b(3)

Limited Life Components:

DOD/DOE b(3)

Intrinsic Radiation:

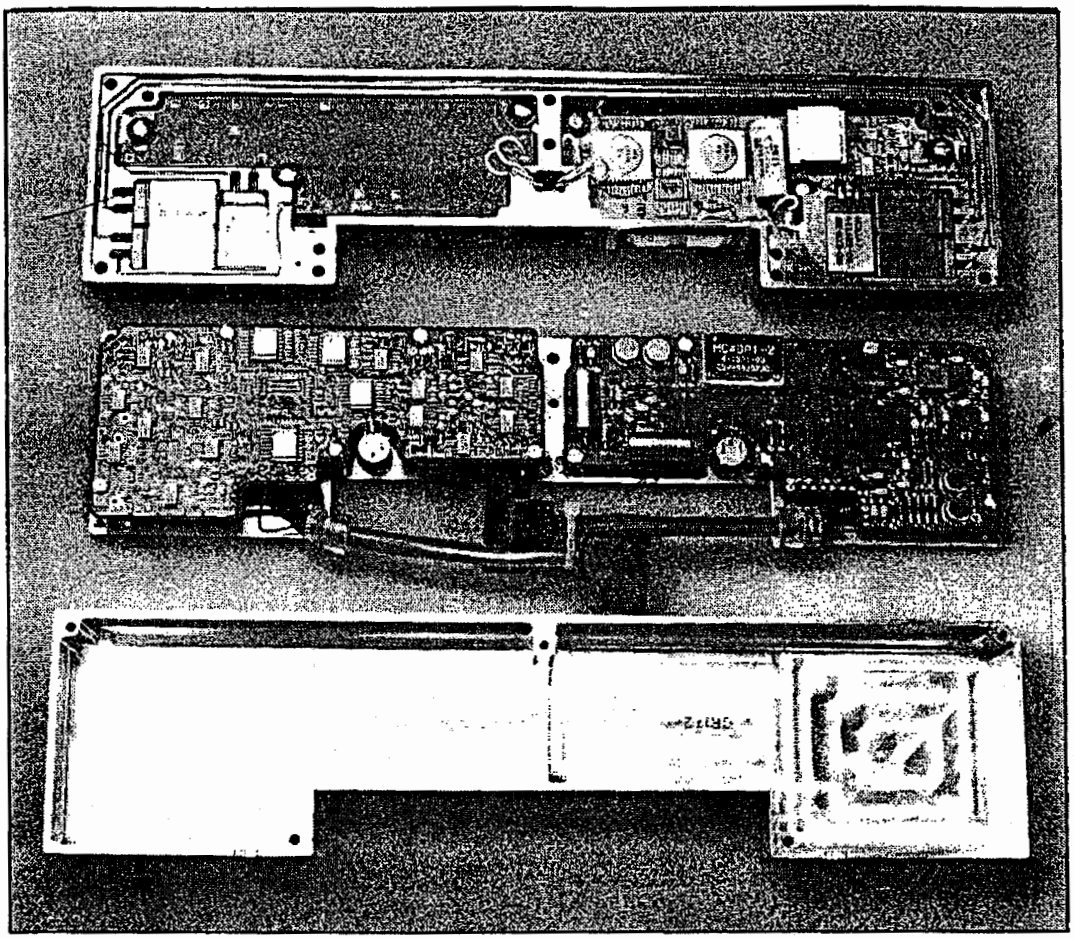
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MC4137 TSSG

The "intent-enabled" design of the MC4137 requires the MC4137 TSSG electronics to "store" the IUQS signal which enables (operates) the MC2969 Intent Strong Link Switch in the firing set during the prearming of the bomb before aircraft release. Until the MC2969 arming sequence is complete, the TUQS signal is not "stored" in the MC4137 electronics. Without the information content of the IUQS signal, the MC4137 cannot formulate the TUQS signal. The strong link/weak-link design and packaging of earlier B61 TSSGs is also retained. Additionally, the new MC4137 "intent-enabled" TSSG is philosophically improved over the earlier TSSGs designed for the B61. Discussion of the nuclear detonation safety of the two TSSG designs appears in Chapter 4.

Figure 18. MC4137 TSSG, Intent-enabled



During prearm of the bomb, the MC4137 TSSG will store the IUQS code in "volatile" memory; without power the code will not be retained. The design of the MC4137 will assure that the IUQS is retained for a minimum of 7 seconds of power loss. If all arming power and monitor power is lost for longer than 7 seconds, the MC4137 will interrupt the arm monitor line to the AMAC. On Navy System 1 aircraft (A-7E and F/A-18), this will result in both the "arm" light and the "safe" light being illuminated when power returns. On the FSA aircraft (A-4M, A-6E,G), the "disagreement" light will illuminate. A power dropout long enough to cause this condition will require the pilot to retransmit the IUQS to "rearm" the TSSG. Power dropouts of shorter duration will not affect the AMAC indications or cause additional pilot workload. The use of "volatile" memory for IUQS retention is a desirable nuclear safety design feature.

Although the B61-6,8 MCs only require compatibility with Navy strike aircraft, the MC4137 TSSG will be designed to be compatible with all aircraft approved for carriage of any B61. Additionally, all aircraft listed in the B90 MCs will be tested for compatibility during development. Demonstration of aircraft compatibility and subsequent incorporation in the B61 ACCD will be restricted to those listed in the MCs.

Whereas the MC4175 TSSG uses two identical, non-conductive assemblies to provide outputs to the two MC2935 Trajectory Strong Link Switches in the firing set, both channels of the MC4137 are packaged in a single conductive enclosure (Figure 18). The materials selected are 304 stainless steel for exclusion region protection and 6061 aluminum for the cover. The single housing is designed to maintain mechanical integrity of the housing, rolamites, and exclusion area electronics in abnormal environments. Isolation of all signals from the case is required.

The top assembly in Figure 18 is the exclusion region containing the rolamites, weak-link ROM, and the circuitry necessary to communicate the ROM pattern through the rolamite contacts to the microprocessor. The circuit board is ceramic. The circuit boards in the middle of figure 18 are identical, with surface mount components on one side (left) and leaded, "through-hole" components on the other. This circuitry is mounted to the steel top of the exclusion region and

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d. Safe Separation Time (SST) Selection - Two independent SSTs, TA and TB are set on the preflight controller. Some AMACs can select between TA or TB. The ICU is designed to store and use this information.

After bomb release, the MC4140 is without power until the rise of the weapon system pulse batteries.

DoE/DoD b(3)

The remaining function of the ICU is to perform the timing and "gate" pulse battery power to initiate the spin rocket or gas generator. After the "deploy" function, the ICU tasks are complete and "shutdown" is commanded.

MC4136 Preflight Controller

DoE/DoD b(3)

The preflight controller also houses the DE1002 Coded Device and MC3246A Thermal Battery (identical to the MC3246[26] in the B61-7 except lithium-silicon/iron disulfide (Li(Si)/FeS_2) electrochemical system is used) for command disable, the J1 connector for PAL operations or interconnecting with the MC4142 Strike Enable Plug, and the PAL voltage regulator. The command disablement and PAL components are described in Chapter 6. The preflight controller is mounted to the preflight bomb subassembly case.

The switch markings and function associated with each switch position are as follows:

TA and TB - For non-laydown deliveries, two independent aircraft safe escape times (TA and TB) are selected. The selection of each requires the manipulation of two digital switches, one for the tens data (1-10) and one for units data (0-9). The maximum safe escape time for the B61 is 69 seconds; therefore, the 7, 8, 9, and 10 switch positions of the tens switch are shorted to the 6 switch deck. Thus, 109 becomes 69, 77 becomes 67, etc. No provision is made to prevent TB settings shorter than TA or vice versa. The selection of the appropriated safe escape time is made from the aircraft during bomb prearm.

Delivery - 2 position; RE,FF
RE - retarded
FF - freefall

Aircraft with FSA AMACs like the Navy A-6E can not override this switch. Arm position selections on the AMAC are limited to AIR and GROUND. System 1 AMACs like the Navy A-7 and A-18 can override this switch; all four delivery options are selectable from the cockpit.

Delay - 3 position; G, H, J

G — 0.3 second deployment delay
H — 0.6 second deployment delay
J — 1.6 second deployment delay

Additionally, positions G and H provide short laydown delay (30 seconds) and position J provides long laydown delay (80 seconds) for aircraft safe escape from laydown deliveries. Discussions at the B61 POM and the B61 Environmental Sugroup have recently addressed the use of "J" by Navy aircraft. Future B61 ACCDs may restrict the use of longer delay times than compatibility tests and analyses have shown to be sufficient to provide separation. No settings longer than the "minimum" times now specified in the ACCD will be approved.

3. System Operation

General

Preflight operations and arming, fuzing, and firing events for the four bomb delivery options are discussed in this chapter. A simplified functional block diagram (Figure 34) and pictorial event sequences for each bomb delivery option (Figures 35-38) are included. Those procedures and electrical system operations that are common to each delivery option are presented below.

Before takeoff, the appropriate switch settings are made on the MC4136 Preflight Controller as described in Chapter 2. At this time, the PAL could be unlocked through the J1 connector of the MC4136 with ground equipment (Chapter 6) or after takeoff if the aircraft is equipped with a PAL-capable AMAC. Complete bomb prearming cannot be accomplished until the PAL is unlocked (i.e., enabled). The MC4142 Strike Enable Plug would be installed. If the aircraft does not contain an IUQS-capable AMAC, the MC3025 Signal Selector must be rotated to the OVERRIDE position.

The bomb may now be prearmed before release by rotating the AMAC selector switch to the desired option position. On FSA/B AMACs, this selector switch provides two positions: air or ground. Retard or freefall is obtained by the delivery switch position on the preflight controller. On System I AMACs like the A-7E and F/A-18, the AMAC has four positions corresponding to the four delivery options: FFA, FFG, REA, and REG. With this capability, the RE/FF Delivery Switch on the MC4136 PFC is overridden.

The F/A-18 AMAC generates a unique train of pulses (IUQS) to drive the MC2969 Intent Stronglink Switch to the closed (enabled) position. Without the AMAC-produced IUQS, the MC2969 will be enabled by the MC3025 Signal

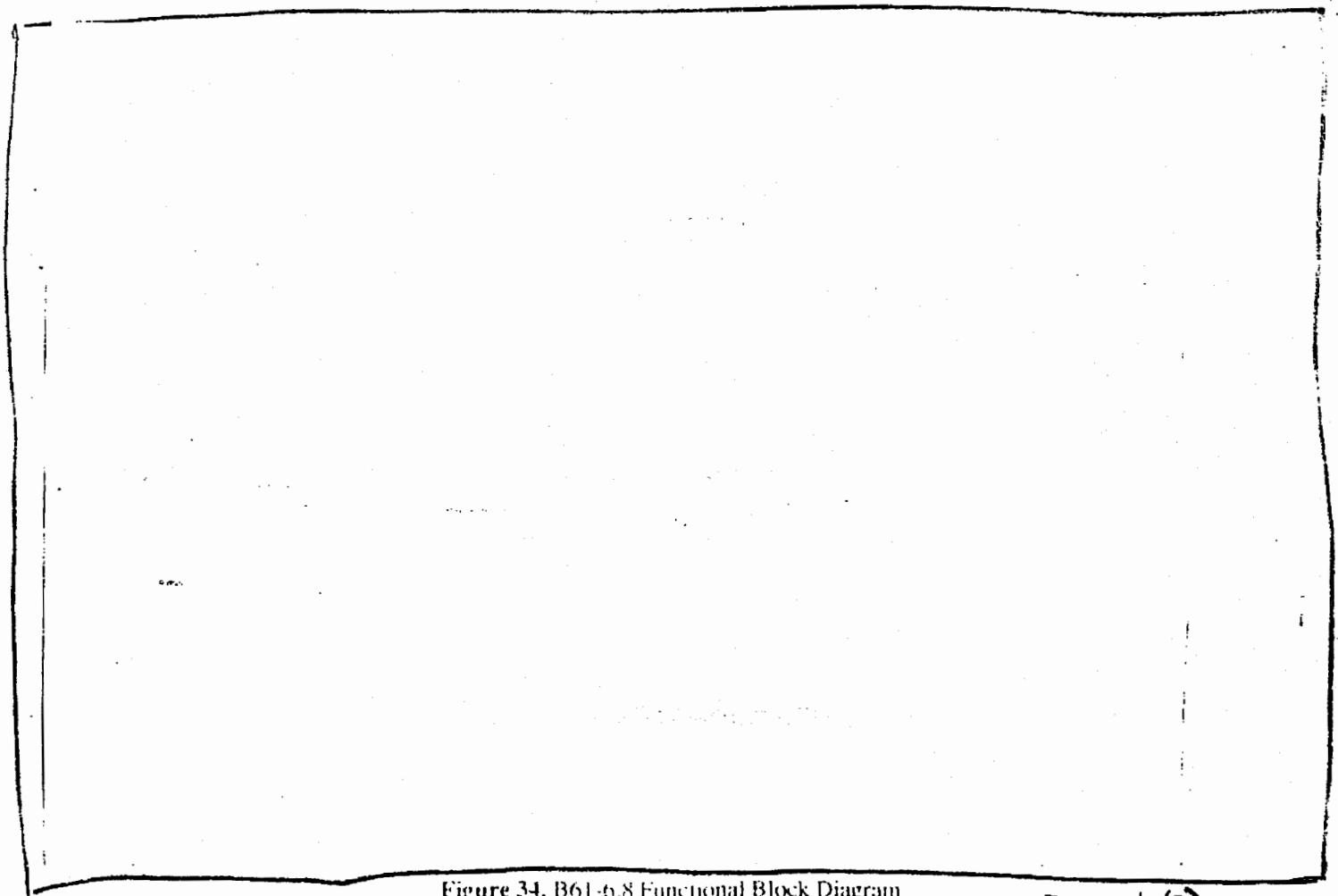


Figure 34. B61-6,8 Functional Block Diagram

DOE b(3)

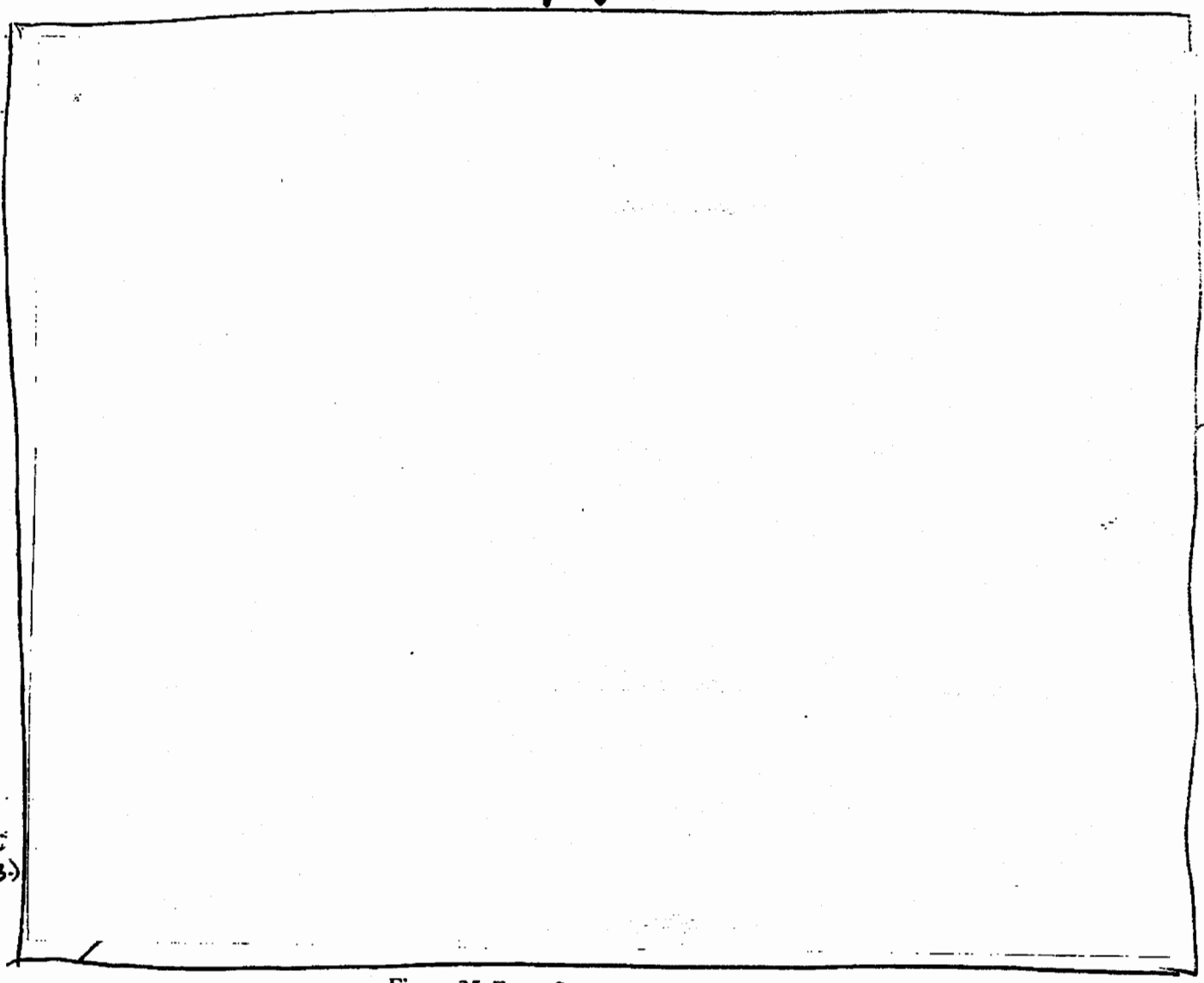


Figure 35. Event Sequence, Freefall Airburst

At safe separation time plus 1.5 seconds, programmer fire circuitry is enabled. Once this occurs, any subsequent radar fire signal will result in the programmer providing closure of the main battery to firing set (A3), causing X-unit discharge which initiates the neutron generator timing circuitry and fires the nuclear primary detonators.

If backup fuzing is selected, at SST plus 1.5 seconds the programmer will also accept impact crystal signals as valid fire signals. If neither radar nor crystal signal is received, the programmer will provide A3 at 120 seconds (design life of the main batteries). If backup fuzing is not desired, the programmer will not deliver A3 if impact crystal signal is received. Contact preclude is not guaranteed. If the bomb impacts the ground with a charged firing set, the X-unit may be triggered by the impact (bypassing the programmer), even if backup were not desired.

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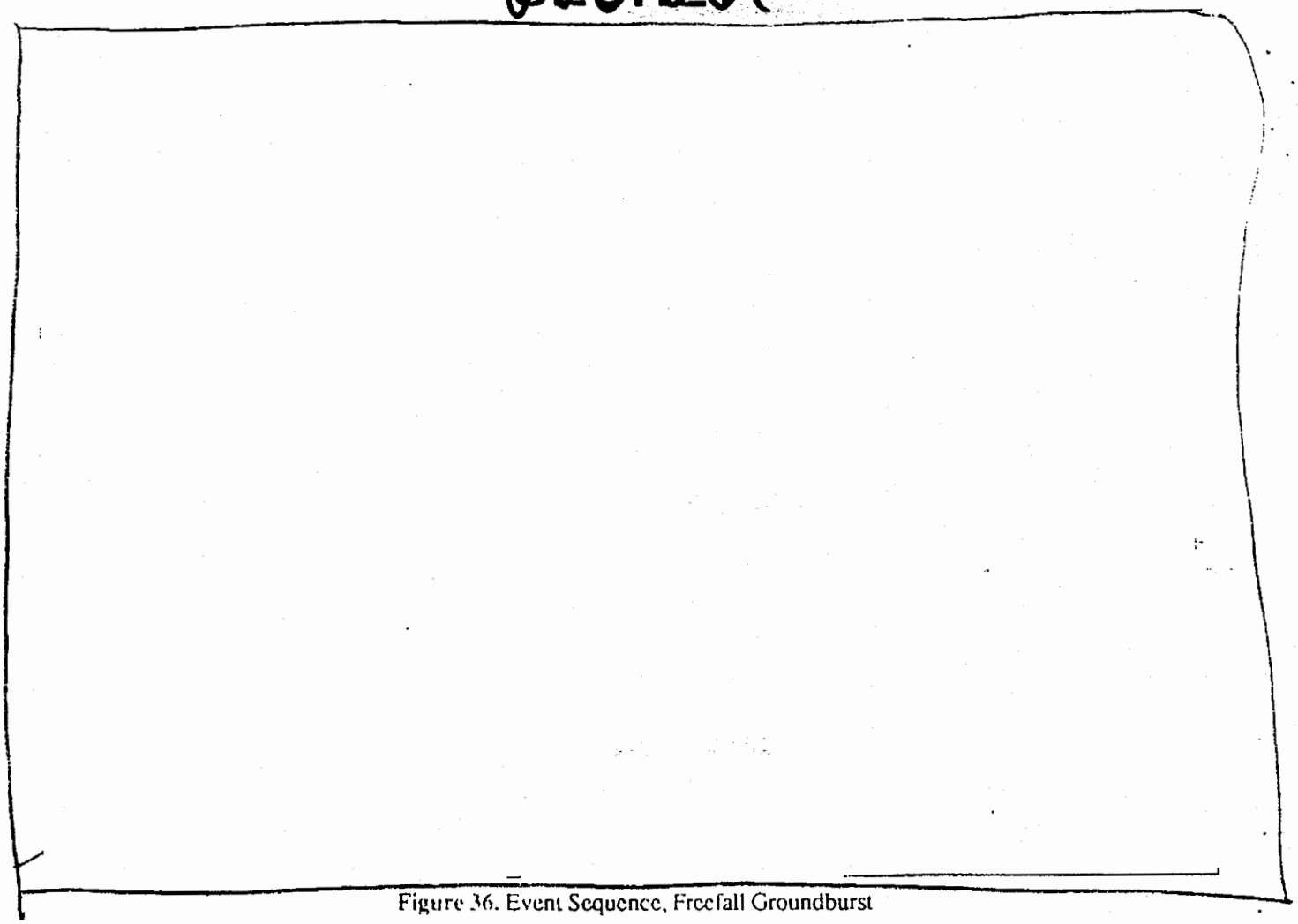


Figure 36. Event Sequence, Freefall Groundburst

Freefall Groundburst (FFG) Delivery

Upon initiation of the spin rocket, the bomb spins to a minimum roll rate of about 3 revolutions per second within about 1 second (Figure 36). The canted fins will sustain the roll rate. This roll rate closes the radial inertial switches (rolamites). At 3 seconds after release, the programmer "gates" main battery power to the MC4175 or MC4137TSSG to drive the MC2935 Trajectory Stronglink Switch in the firing set.

The aircraft-selected safe separation time (SST) has been previously communicated by the ICU to the programmer.

At safe separation time minus 3 seconds, the programmer connects main battery power to the transverter oscillator in the firing set (A1). At safe separation time, similar programmer circuitry connects main battery power to the firing set transverter (A2). With these two inputs, each electronic transverter can charge the 2.0- μF firing set X-unit capacitor and the 0.6-μF neutron generator capacitors to approximately 3300 V and 2400 V, respectively, in less than 1.2 seconds.

At safe separation time plus 1.5 seconds, programmer fire circuitry is enabled. Once this occurs, the subsequent crystal fire signal will result in the programmer providing closure of the main battery to the firing set (A3), causing X-unit discharge which initiates the neutron generator timing circuitry and fires the nuclear primary detonators.

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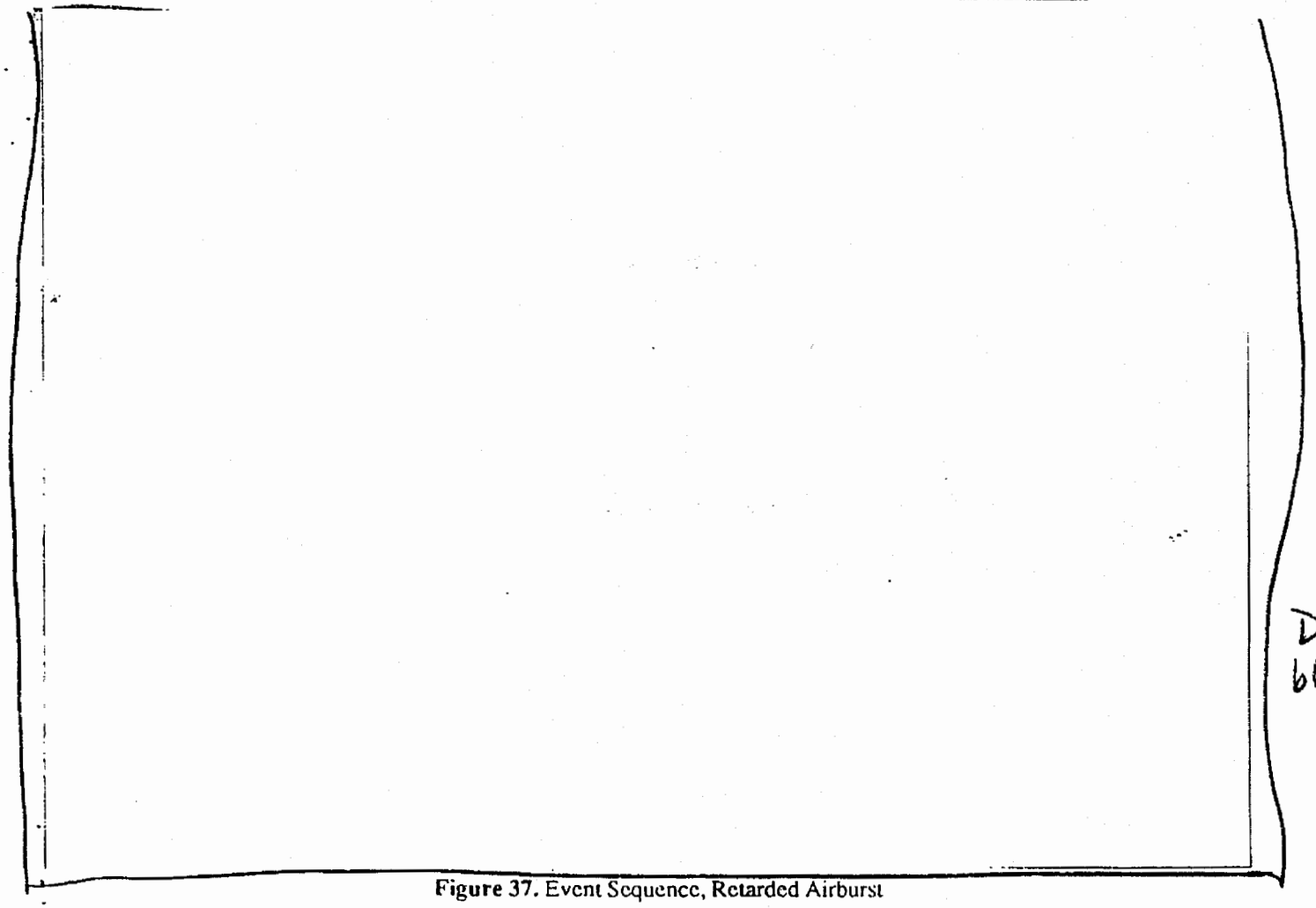


Figure 37. Event Sequence, Retarded Airburst

Retarded Airburst (REA) Delivery

Firing the gas generator into the volume enclosed by the telescoping tubes starts the parachute deployment process (Figure 37). The deceleration produced by the deployed parachute closes the longitudinal nonlatching inertial switch (rolamite). The design of the rolamite guarantees a closure time greater than the maximum required (0.734 seconds) for the MC4175 or MC4137 TSSG to enable the MC2935 Trajectory Stronglink Switch in the firing set.

The aircraft-selected safe separation time (SST) has been previously communicated by the ICU to the programmer. At 7 seconds before SST, the programmer "gates" main battery power to the radar and at 4 seconds before SST, the programmer activates circuitry to communicate height of burst selection to the radar.

[redacted]

At safe separation time minus 3 seconds, the programmer connects main battery power to the transverter oscillator in the firing set (A1). At safe separation time, similar programmer circuitry connects main battery power to the firing set transverter (A2). With these two inputs, each electronic transverter can charge the 2.0- μF firing set X-unit capacitor and the 0.6-μF neutron generator capacitors to approximately 3300 V and 2400 V, respectively, in less than 1.2 seconds.

If backup fuzing is selected, at SST plus 1.5 seconds the programmer will accept either a radar fire or impact crystal signal as a valid fire signal. Activation of the impact crystal at parachute-retarded terminal velocities (80 fps) will not be reliable in all terrain. If neither radar nor crystal signal is received, the programmer will provide A3 at 120 seconds (design life of the main battery).

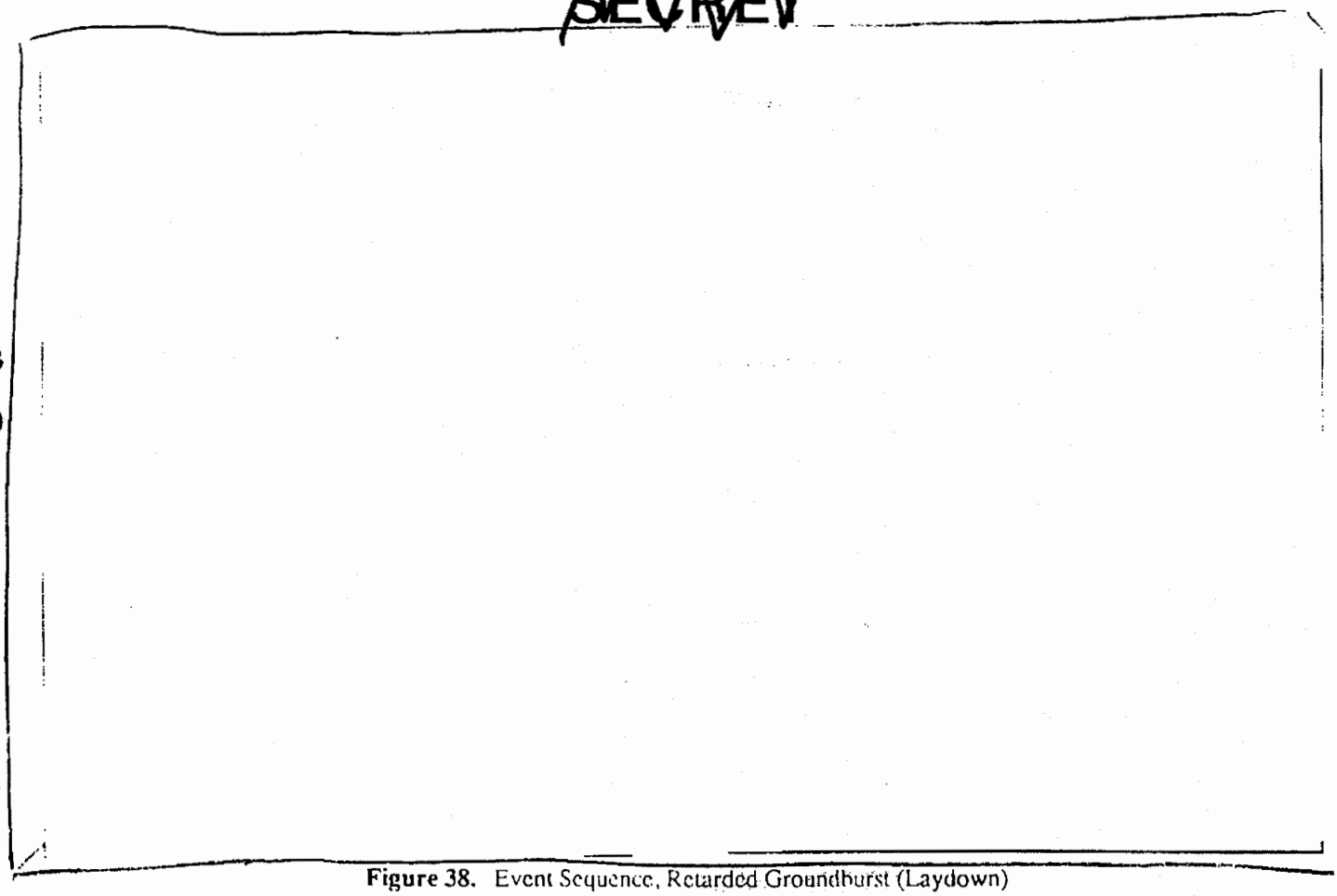


Figure 38. Event Sequence, Retarded Groundburst (Laydown)

Retarded Groundburst (REG) or Laydown Delivery

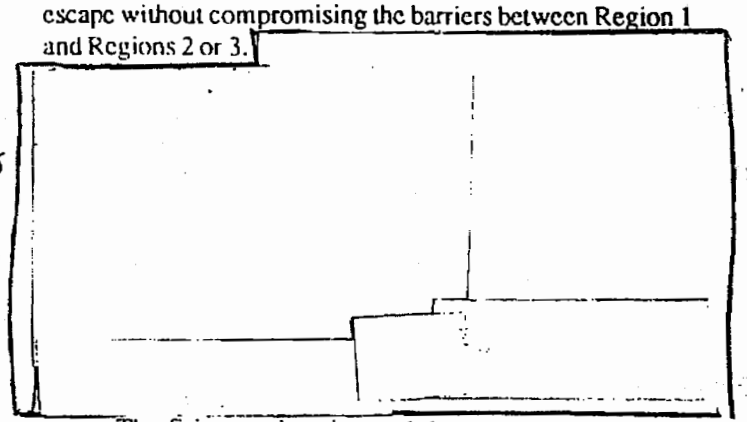
Firing the gas generator into the volume enclosed by the telescoping tubes starts the parachute deployment process (Figure 38). The deceleration produced by the deployed parachute closes the longitudinal nonlatching inertial switch (rolamite). The design of the rolamite guarantees a closure time greater than the maximum required (0.734 seconds) for the MC4175 or MC4137 TSSG to enable the MC2935 Trajectory Stronglink Switch in the firing set.

For the laydown delivery mode, the safe separation times selected on the preflight controller do not apply. Aircraft safe escape maneuvers are instead constrained by the laydown delay time, which is 30 seconds or 80 seconds. Selection of G or H deploy time results in a 30-second delay, whereas J provides an 80-second delay. As discussed earlier, selection of J may be restricted in the B61 ACCD except for aircraft requiring that time to ensure safe escape.

At safe separation time minus 3 seconds, the programmer connects main battery power to the transverter oscillator in the firing set (A1). At safe separation time, similar programmer circuitry connects main battery power to the firing set transverter (A2). With these two inputs, each electronic transverter can charge the 2.0- μF firing set X-unit capacitor and the 0.6-μF neutron generator capacitors to approximately 3300 V and 2400 V, respectively, in less than 1.2 seconds.

At safe separation time plus 1.5 seconds, the programmer will provide closure of the main battery to firing set (A3), causing X-unit discharge which initiates the neutron generator timing circuitry and fires the nuclear primary detonators.

As shown in Figure 39, the sealed covers of Region 1 of the firing set are not on the same surface as the covers for Regions 2 and 3. This allows hot and possibly conductive gases generated in Region 1 by an abnormal environment to escape without compromising the barriers between Region 1 and Regions 2 or 3.



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b(3)

The firing set housing and detonator cable cover is fabricated from fiberglass-reinforced, compression-molded MXB-71. MXB-71 is fire-resistant with excellent dielectric strength properties for temperatures up to 500°C. The openings in the barriers for the functional stronglink switch contacts and necessary openings into Regions 2 and 3 for test or reset of the MC2935s are sealed with high-temperature silicone. The metal mounting screws for the stronglink switches are through the container wall and are similarly closed from the exterior of the firing set by plugs of MXB-71 sealed with the same silicone.

To assure protection of the firing set exclusion regions by the stronglink switches, the contact assembly of each switch is constructed of metal and ceramic parts. The free volume is minimized to avoid bridging between input and output contacts by unintended conductive paths during abnormal thermal and crush environments. The switch housings are made of high-strength stainless steel to resist deformation in crush environments. The MC2969 and MC2935 can each withstand at least 1600 V dc at temperatures up to 400°C. Both switches contain discriminator mechanisms that, upon receiving an incorrect input signal, lock the switch in the open position. The MC2969 is resettable, requiring a pulse of correct length and amplitude to return the discriminator mechanism to its initial state. To be reset, the MC2935 requires both a manual release and a specific electrical signal input. Because physical access to the firing set is required, this procedure can only be done at a DOE manufacturing facility.

MC Requirements

Normal Environments

The B61-6,8 military characteristics state:

"The probability (per bomb lifetime) of a premature nuclear detonation for the normal environments described in the STS shall not exceed:

1. Prior to prearm (which includes application of the arming power and the unique intent enabling stimulus) and prior to release from the aircraft and in the absence of the trajectory stimulus, 1×10^{-9}.
2. After prearm and prior to release from the aircraft, and in the absence of trajectory stimulus, 1×10^{-6}.
3. After prearm and after release from the aircraft, and in the absence of the trajectory stimulus, 1×10^{-3}.

The probability (per occurrence) of a nuclear detonation in the normal release envelope after receipt of the trajectory stimulus shall not exceed:

1. Prior to expiration of the safe separation time, 1×10^{-3}.
2. After expiration of the safe separation time and prior to the intended detonation, 1×10^{-2}."

Abnormal Environments

The military characteristics for the B61-6,8 state:

"The probability (per occurrence) of a nuclear detonation of a bomb for individual or credible combinations of abnormal environments specified in the STS shall not exceed:

1. In the absence of any unique intent and trajectory stimuli, 1×10^{-6}.
2. After receipt of the unique intent and in the absence of the trajectory stimulus, 1×10^{-3}.
3. Placing the normal/override switch in the override position shall be considered intent enabling stimulus."

Safety Subsystems

Fault tree analysis techniques are useful for defining and evaluating the nuclear safety design of the bomb system. Figures 40 through 43 are abbreviated examples of fault trees. These figures illustrate the three safety subsystems incorporated in the B61-6,8 to meet nuclear detonation safety requirements in normal and abnormal environments. Both DOE (Sandia, Los Alamos, and production agencies) and DoD requirements are addressed.

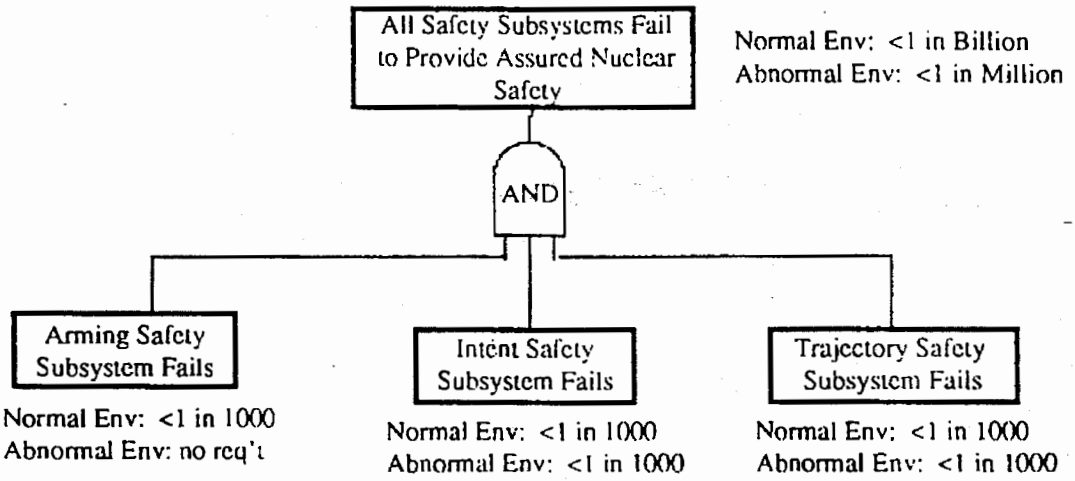


Figure 40. Fault Tree, Loss of Electrical System Safety

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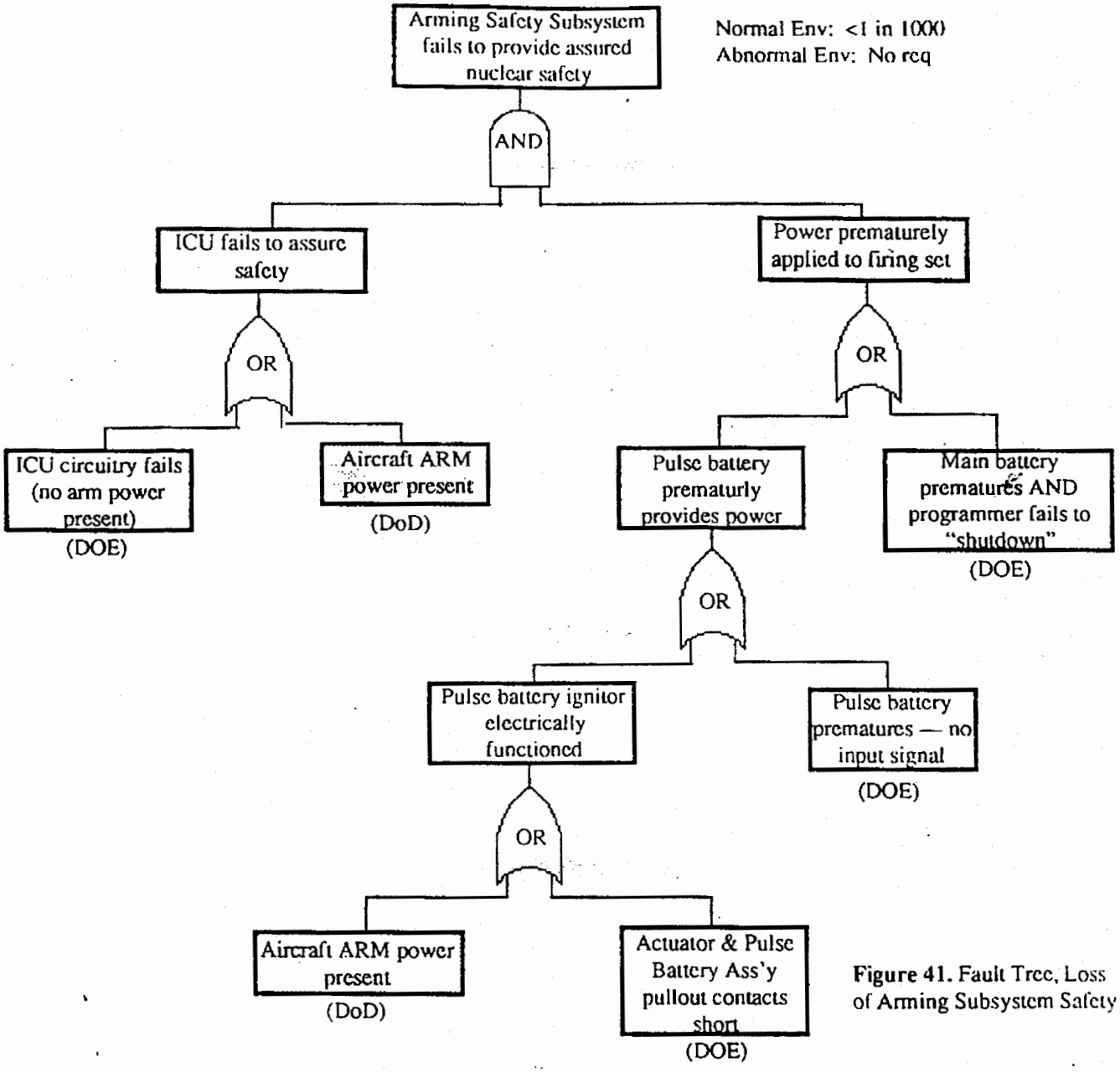


Figure 41. Fault Tree, Loss of Arming Subsystem Safety

Arming Safety Subsystem

The arming subsystem, when combined with the intent and trajectory subsystems, provides the additional 1×10^{-3} nuclear detonation safety to achieve the MC requirements in normal environments. No abnormal-environment nuclear detonation safety requirements are placed on this subsystem. This subsystem prevents the application of normal environment aircraft and bomb electrical system signals to critical circuits. Electrical signals at the bomb umbilical and preflight controller connectors are restricted to prescribed PAL or stronglink monitor signals from the aircraft or T-gear.

The component assemblies included in the arming subsystem are the MC2213(A) Actuator and Pulse Battery Assembly, the MC2238A/B Pulse Batteries, the MC3656 Main Batteries, MC4138 Programmer, and the MC4140 ICU. The delivery option selection circuitry and the ICU software provide positive control of the output of the pulse batteries. Premature actuation of a pulse battery will result in system "shutdown" without the required aircraft delivery option voltage being present. Premature of the main battery will similarly result in system "shutdown" by the programmer. Both premature actuation of the pulse battery and aircraft prearm power must occur for the ICU and programmer to function in the intended use mode. For the arming safety subsystem, the DoD must insure that prearm dc-power is not applied to the umbilical connector. The DOE will insure the components involved meet the design requirements.

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Intent Safety Subsystem

As shown in figure 42, both the DoD and DOE must meet requirements for the Intent Safety Subsystem to provide assured nuclear detonation safety. The DOE must assure that the MC2969 ISLS in the firing set meets the isolation requirements and is only enabled upon the application of the IUQS. The DoD must assure that the IUQS signal is not generated prematurely due either to inadvertent or inappropriate human action or hardware malfunction of the IUQS generator in the AMAC. Both DOE and DoD must meet these requirements in the event of an abnormal environment.

If the MC3025 Signal Selector is in the OVERRIDE position, there are no requirements of the intent safety subsystem to provide protection in an abnormal environment. With the selector in OVERRIDE, the bomb will meet only a 1×10^{-3} probability of a nuclear detonation in an abnormal environment. Additionally, 1×10^{-3} probability of a nuclear detonation can only be met in the "absence of the trajectory stimulus."

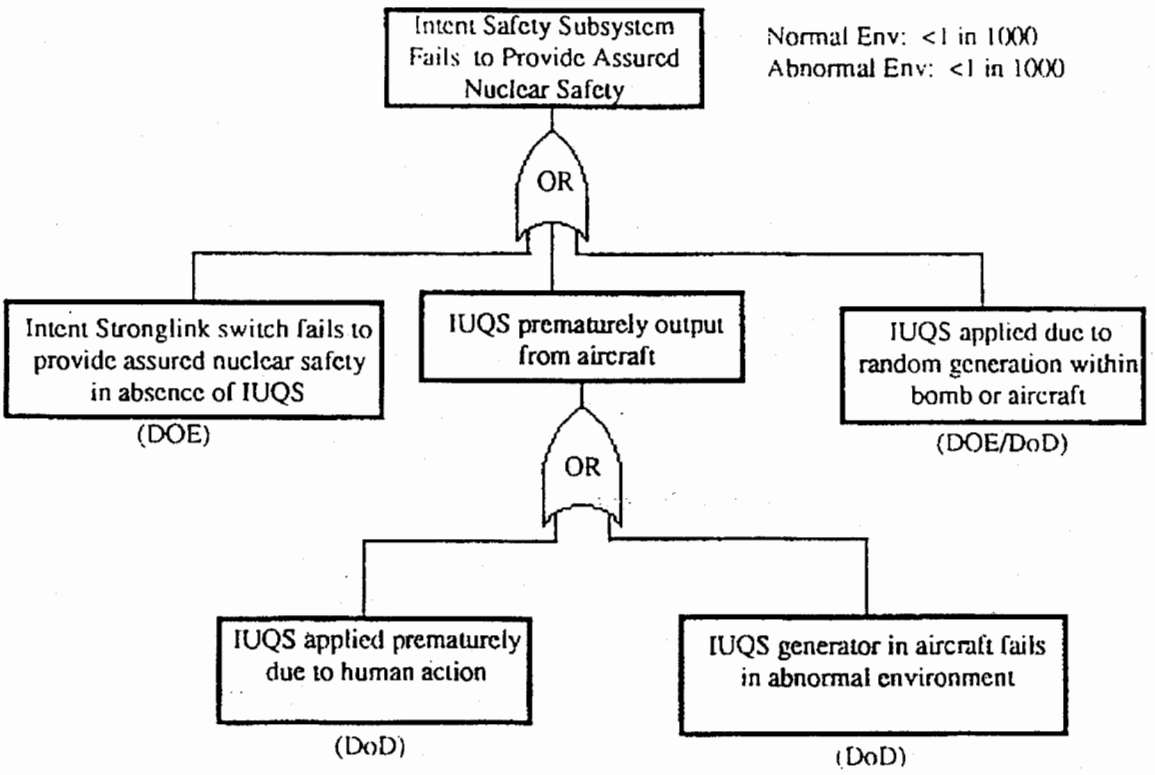


Figure 42. Fault Tree, Loss of Intent Subsystem Safety

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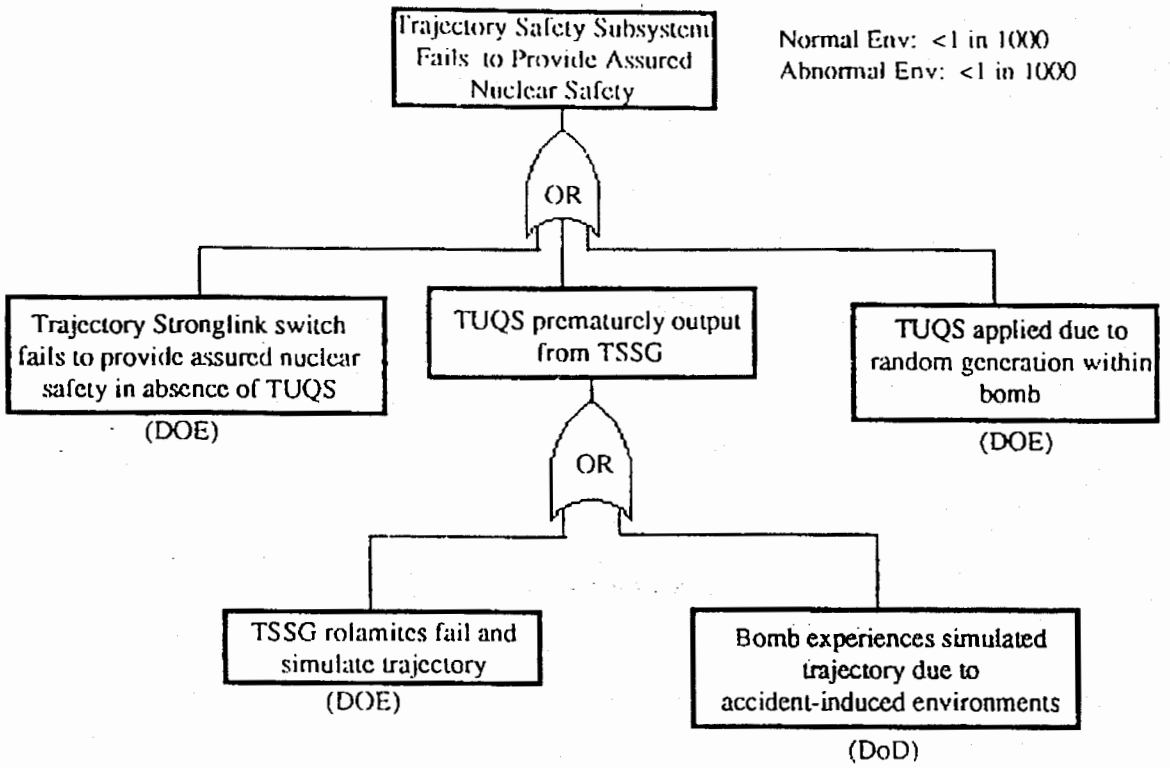


Figure 43. Fault Tree, Loss of Trajectory Subsystem Safety

Trajectory Safety Subsystem

Of the three nuclear safety subsystems, arming, intent, and trajectory, only the trajectory safety subsystem is composed entirely of DOE hardware. The DoD responsibility is to assure that no accidental simulation of the "intended use" environment (retardation or spin) occurs. Major components within this safety subsystem are the MC4175 TSSG or the MC4137 TSSG and the MC2935 Trajectory Strong-Link Switch in the firing set. The MC4175 TSSG is identical to the MC3640 TSSG (B61-7) except for a connector change and will support B61-6 production for the first six months until the MC4137 TSSG is available.

MC4175

The MC4175 TSSG is a second-generation design of trajectory sensing devices incorporated into B61 bombs to enable (close) the MC2935. In the mid-70's, the MC2948 TSSG was designed for first use in the B61-5 and was later used on the B61-3,4. Both the MC2948 TSSG and MC4175 TSSG use "stronglink/weak-link" design philosophy to achieve nuclear safety in abnormal environments. The normally open, acceleration-sensing rolamite switches (stronglinks) interrupt electrical power from the TSSG electronics that generate the trajectory unique signal (TUQS). The application of power through the inertial rolamite switches to the electronics will produce the TUQS to drive the MC2935. Thus the design theme requires that the TSSG rolamite switches (stronglinks) be capable of surviving, without shorting, higher levels of shock or temperatures produced by an accident environment than the TUQS-producing electronics/ceramic circuit board (weak-link). Failure of the stronglinks in severe environments is acceptable, but only if the weak-link also fails irreversibly.

Figure 44 is a simplified block diagram of the trajectory safety subsystem with the MC4175 TSSG which illustrates the electrical connection for both the parachute retarded and spin-stabilized freefall delivery modes of the bomb. Functional contacts of the MC2969 Intent Strong-Link Switch are required to be closed before the TUQS can drive the MC2935. Both the intent and trajectory safety subsystems are designed to meet a goal of 10^{-3} given an abnormal environment; each is considered to be independent and no contribution to the trajectory safety subsystem because of the interruption of the MC2935 drive lines by the MC2969 is assumed. In the spin-stabilized bomb delivery mode, one radially oriented rolamite switch in each of the two TSSGs must close before the series circuit is closed between the bomb power source and the TUQS-producing electronics. The two MC4175 TSSGs are mounted opposed to each other equidistance from the

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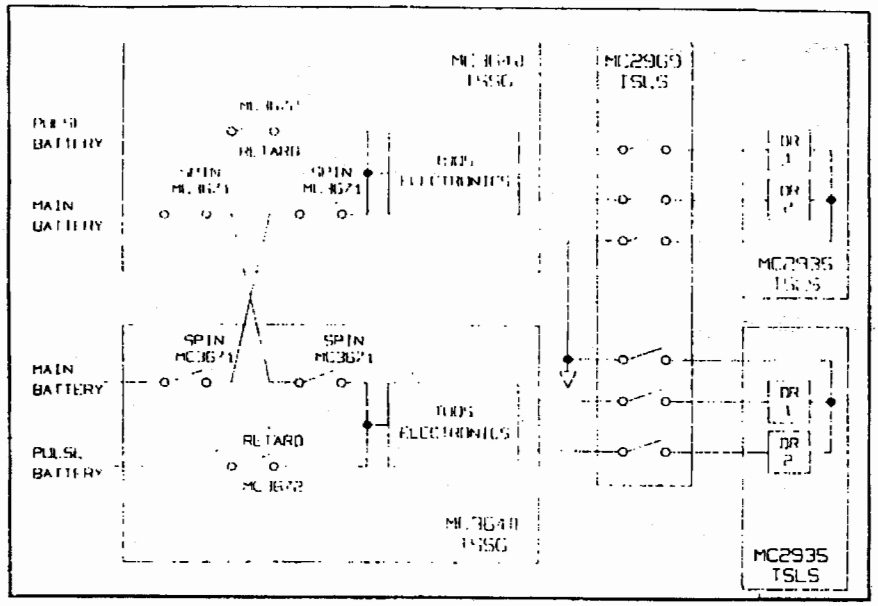


Figure 44. Block Diagram, Trajectory Safety Subsystem with MC4175 TSSG

bomb's longitudinal center line so that a radial acceleration or deceleration may cause both of the radially-mounted rolamites in one TSSG to close, but the spin rolamites in the opposite TSSG will remain reset. Spinning of the bomb is required to close all four spin rolamites.

Numerous shock tests of the MC3671 (spin) and the MC3672 (retard) rolamites have revealed the MC3671 to be most susceptible to shock: 4000g, 1ms when the direction of the shock causes the rollers to travel from the reset end (resting end) to the actuate end. The heavier rollers of the MC3671 travel to the actuate end with sufficient velocity/energy to separate the end cap from the case. In all other directions the MC3671 is 6000g's or greater, as is the MC3672 in all directions, including the actuate direction.

By design, the ceramic printed wiring board for the TUQS electronics is the weak-link for the MC4175 TSSG in the shock environment. The two-sided bonding of the DAP rolamites to the mica housing of the MC4175 TSSG insures minimum failure levels of approximately 6000g's. Whereas shocks perpendicular to the ceramic board result in breakage at as low as 330g, shocks in the plane of the board do not result in predictable failures (fracture). Abnormal environment testing of the ceramic boards have shown boards to survive ~7000g's in the plane of the board (undesirable since the stronglink rolamites can fail at lower levels). However in no system test nor component-level testing of complete MC3640 TSSGs for the B61-7 did there exist an "unsafe" condition. Some abnormal environment tests have resulted in damaged rolamites and/or lack of adhesion to the exclusion region barrier and an undamaged circuit board, but none exhibited a short circuit that could transmit power to the electronics. With the actuate contacts on one end of the rolamite, bypass requires the band or roller to remain at the actuate end. None of the damaged rolamites exhibited a potential for that condition.

Two polycarbonate capacitors, essential components for the generation of the TUQS, are used as the thermal weak-link. Both the DAP rolamite and the glass-bonded mica housing of the MC4175 TSSG retain excellent electrical insulative properties to the structural limit of the materials in high thermal environments. With a repeatable and irreversible failure temperature of 350° to 400°F, the polycarbonate capacitors will fail long before bypass of the rolamites or the housing is possible.

It is important to note that "trajectory sensing" implies the parachute was deployed and the resultant retardation forces were sufficient to close the rolamite switch or the bomb spin rate is adequate to close similar, radially oriented rolamite switches. No discrimination capability between an "intended use" and a "trajectory" resulting from an accident is possible. Any airborne accident can result in damage to the bomb tail section and resultant parachute deployment or adequate spin rates developing due to the bomb fin cant necessary to maintain roll rate for accuracy in freefall deliveries.

MC4137 TSSG

Where the MC4175 depends solely on the stronglink/weak-link design philosophy, the MC4137 also incorporates "intent-enablement" as a safety enhancement. The "intent-enabled" design of the MC4137 requires the MC4137 TSSG electronics to "store" the IUQS signal which enables the MC2969 Intent Strong Link Switch in the firing set during the prearming of the bomb before aircraft release. The TUQS signal is not "stored" in the MC4137 electronics. Without the information content of the IUQS signal, the MC4137 cannot formulate the TUQS signal. The strong link/weak-link packaging of the TSSG is also retained since the "intent-enablement" is a nuclear safety "enhancement." The trajectory safety subsystem is required to provide 1×10^{-3} protection in abnormal and normal environments requiring independence of the three safety subsystems. The strong link/weak-link packaging of the TSSG will be addressed during development as rigorously as would be required if the TUQS were "stored."

To improve the packaging for abnormal environments, both channels of the MC4137 are packaged in a single steel/aluminum enclosure (Figures 18 and 45). Conductive housing and barriers of steel are used to maintain mechanical integrity in abnormal environments. The steel housing, exclusion region barriers, and rolamites are electrically conductive and designed to divert unintended, accident-induced energy to ground. Isolation of all signals from the case is required in normal environments for reliability.

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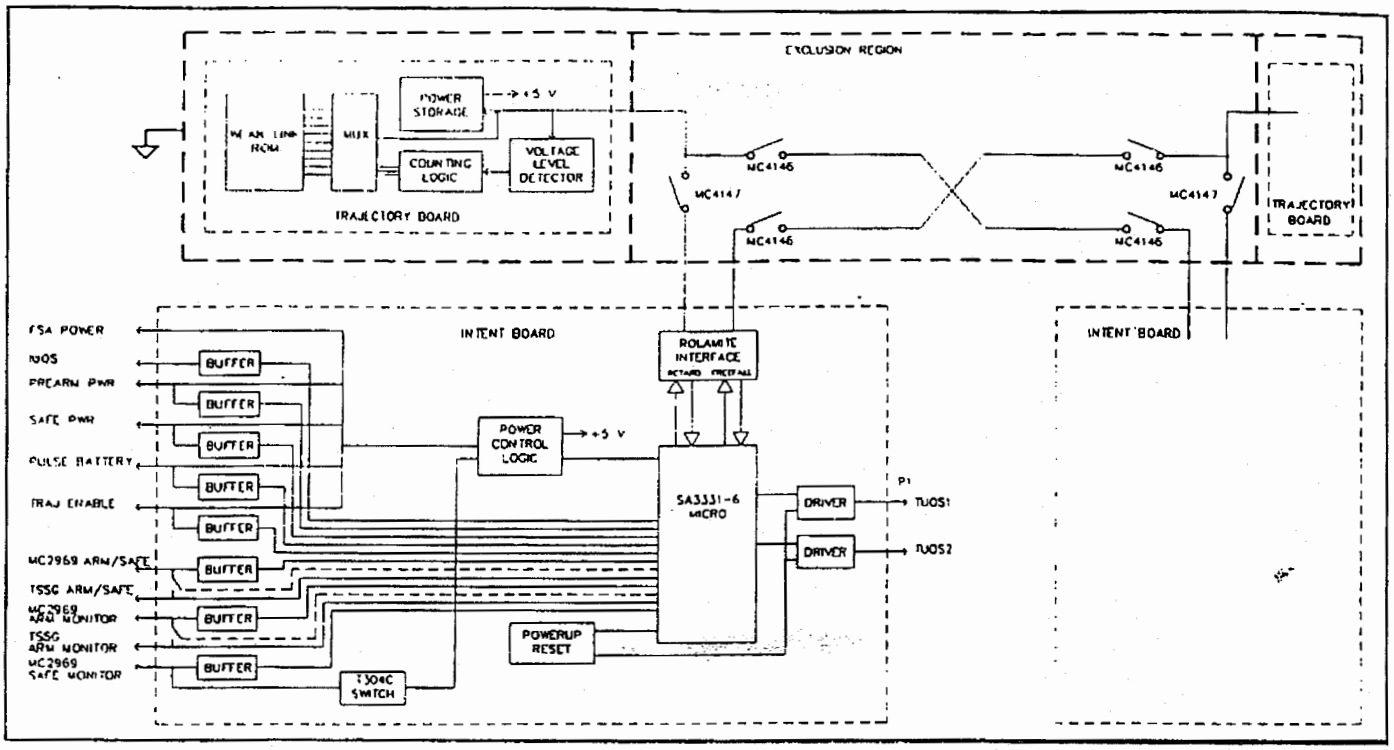


Figure 45. Block Diagram, Trajectory Safety Subsystem with MC4137 TSSG

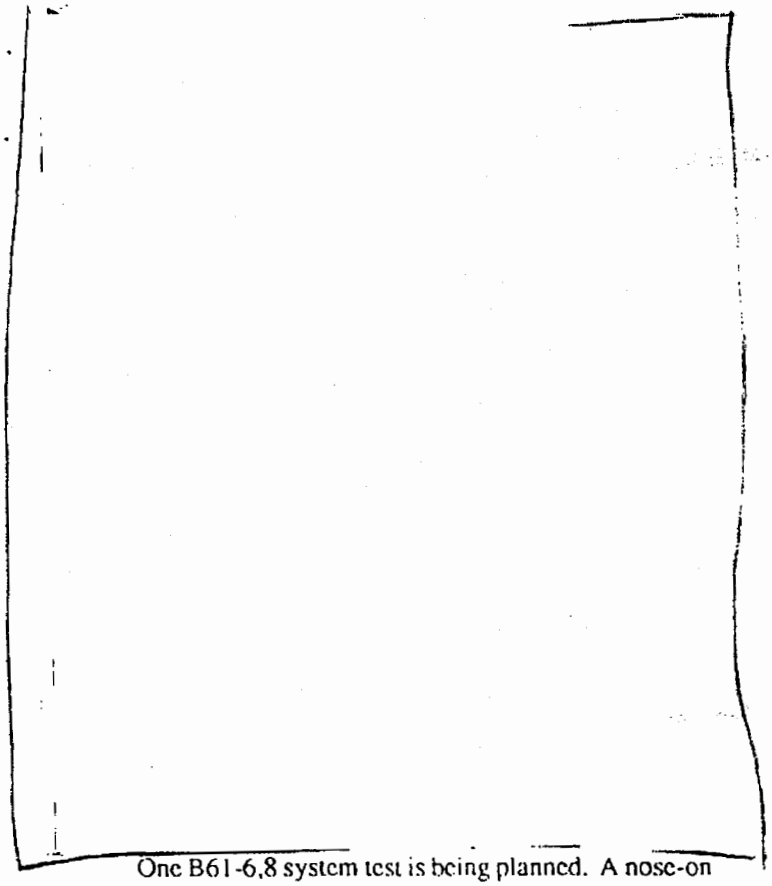
Both of the new rolamites in development (MC4146 to sense bomb spin and MC4147 for retarded drops) are steel-case, hermetically sealed assemblies. As in the MC4175, there are two spin rolamites per channel connected in series, diametrically opposed in the bomb to require true spin of the bomb. Previous rolamite designs have been constructed of insulative materials with the conductive band as the signal (power) path between the actuate contacts. The new rolamites are designed for increased ruggedness and predictability in abnormal high shock environments. The steel rolamites and TSSG housing (exclusion region barrier) will each incorporate mechanical mounting features that will insure integrity of the rolamite/barrier union through all abnormal environments. This design will result in the rolamite case electrically grounded to the housing (system ground). Therefore the contact block in the roller is required to be isolated from the roller and the band. The required electrical path is through the pins and the contact block (see Chapter 2).

In the block diagram (Figure 45) shown above, the exclusion region encompasses the rolamites, weak-link ROM, and circuitry necessary to interface with the SA3331-6 microprocessor. Each "intent board" is packaged outside the exclusion region and contains the aircraft interface circuitry, microprocessor, and TUQS drive circuits. To format the TUQS signal, each independent channel of the MC4137 TSSG (an intent board and a trajectory board plus three rolamites) will combine the information from the IUQS signal stored in the microprocessor with 24 bits stored in a thermal weak-link ROM (read only memory). Low melt alloy loops on a printed circuit board (Figure18) form the 24 bits of the weak-link ROM. Melting of the "loops" in high temperatures from abnormal environments will result in either opening or shorting to the board. Either alternative is "safe"; combining with the IUQS signal would lock up the MC2935 TSLS. Early thermal testing of the TSSG has recently led to redesign of the housing and weak-link ROM to mount the ROM to the outer wall of housing. An instrumented unit with representative rolamites and housing indicated the weak-link ROM would reach guaranteed failure temperature as the rolamite temperature was approaching its design temperature limit of 500°F, with the ROM mounted on the ceramic board. Mounting of the ROM near the outer TSSG wall resulted in considerable margin.

An additional nuclear safety enhancement achieved in the design of the MC4137 TSSG is the use of "volatile" memory (without power the IUQS code will be lost) to store the IUQS code during the prearm of the bomb. A permanent memory ("non-volatile") would require certification of the erasure of the IUQS after in-process, acceptance, and system level testing. On a "first principles" basis, the incorporation of the "volatile" memory is most attractive and defensible from a nuclear detonation safety standpoint. Capacitive "hold up" energy storage in the MC4137 will assure that the IUQS is retained for a minimum of 7 seconds in the event of an intermittent aircraft power dropout. If all arming power and monitor power is lost for longer than 7 seconds minimum

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One B61-6,8 system test is being planned. A nose-on impact test at a velocity (to be determined) greater than the last B61-7 test (328 fps) and less than 492 fps will be conducted to confirm the extrapolations made on the B61-7 test. This test unit may also be used to investigate the effect of combined abnormal environments (thermal followed by impact).

Of the new components in development to support the B61-6,8, only the MC4137 TSSG has abnormal environment requirements. The weak-link ROM will be characterized in shock on both component-level testing and system tests where appropriate.

Crushing

This environment is a semi-static situation where, for example, during an accident a structural member of the aircraft comes to rest on the weapon case.

Design Theme. The MC2969 and MC2935 stronglink switches are required to hold off any energy reaching the fire set in this environment. With the structural properties of the thick aluminum center case and the steel support sleeve serving to protect the exclusion region from direct exposure to the outside world in any credible static crush abnormal environment, no weak-link needs to be identified.

Response Analysis/Tests. Tests conducted on the B61-5 and the B61-3,4, each with the identical center case (but with different support sleeve designs), showed almost linear deformation with applied load until case rupture at 305,000 lbs and 335,000 lbs, respectively. In each test, loading was applied through a rigid 2-inch bar placed perpendicular to the longitudinal axis of the bomb over the firing set. In accident possibilities for the B61-6,8, the forces necessary to rupture the center case do not exist. For example, a fully loaded B-52 weighing about 500,000 lbs could rest at most one-half or 250,000 lbs on a B61-6,8. Maintaining the integrity of the center case, with the stronglinks ensuring electrical isolation to the practical limit of the environment, assures meeting the 1 in 10^6 safety requirement.

Thermal

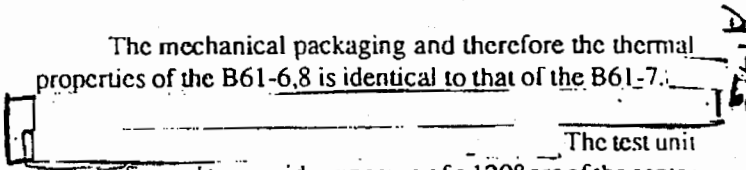
Complete or partial bomb engulfment by a JP-series kerosene (jet fuel) fire is possible. Fuel supplies are assumed to be sufficient to allow all processes to run to completion.

Design Theme. In abnormal thermal environments, predictable nuclear safety is accomplished by stronglink/weak-link colocation within an exclusion region whose barriers primarily consist of a high-temperature insulation material, MXB-71, and ceramic dielectric in the stronglink switches. The applicable weak-links are the X-unit capacitor and the nuclear system high explosive and detonators.

Response Analysis/Tests. Tests demonstrating safe response in abnormal thermal environments conducted during the B61-3,4 program included the following:

- High-temperature tests on switches and barriers up to 1000°F
- High-temperature tests on weak-links (capacitors and IHE) to determine failure threshold
- High-temperature tests on 12 firing sets at temperatures up to 1850°F
- High-temperature tests on four B61-3,4 test units.

The mechanical packaging and therefore the thermal properties of the B61-6,8 is identical to that of the B61-7.



The test unit was configured to provide exposure of a 120° arc of the center case directly to the fire with the remaining portion of the bomb exterior insulated and protected from direct flames. In this way, the most preferential heat path to the stronglink switches is obtained and therefore a worst-case test results. The thermocouple data (Figure 46) indicated the desired close thermal-tracking of the stronglink and weak-link temperatures. Thermocouples within the IHE indicated that in this orientation the IHE starts burning before the X-unit capacitor reaches failure temperature. The bomb IHE was totally consumed in the fire without detonating. Posttest examination of the firing set revealed total thermal destruction of the mylar X-unit capacitor while the stronglinks retained voltage

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Combined Abnormal Environments

The B61-6,8 MCs require nuclear detonation safety be achieved "for individual or credible combinations of abnormal environments specified in the STS." The applicable STS for the B61-6,8 has been distributed for comments and revision. The section defining credible combined abnormal environments is being discussed and a revision has been proposed. Therefore the specific STS guidance to which the design and evaluation program for the B61-6,8 will be judged is not available.

The bombs response to combinations of abnormal environments relies on the demonstrated safe response to individual abnormal environments by virtue of the stronglink/weak-link/exclusion region design concept. For all single abnormal environments identified in the STS, it has, or will be shown that either the weak-link elements of the nuclear system or firing set become irreversibly inoperable prior to the stronglink failure, or the stronglinks maintain electrical isolation. Additionally, the relative stronglink/weak-link failure levels are sufficiently separated so that an abnormal environment not severe enough to disable the weak-link is below the level necessary to degrade the stronglink/exclusion region isolation. Thus, there are two predictably safe responses to an abnormal environment that have a direct bearing on system response to sequential exposure to abnormal environments:

1. The weak-link has become irreversibly inoperable prior to stronglink failure or bypass.
2. The stronglinks remain intact (the weak-link has not failed).

Given response #1, bomb exposure to subsequent abnormal environments would not result in a nuclear detonation since the system was rendered inoperable by the initial exposure.

Given response #2, the bomb is expected to withstand additional abnormal environments terminating in a safe condition with either the stronglinks intact or with the weak-link inoperable prior to stronglink failure or bypass.

There has never been a entire bomb system exposed to an ordered sequence of abnormal environments. There has been abnormal environment testing performed at the major component level (e.g., the firing set) to identify potential problem areas. Numerous tests have been performed on the MC2918 Firing Set to establish structural properties and dielectric properties of the stronglink/exclusion region following a high thermal abnormal environment. There are development activities in progress to improve the structural support of the stronglink switches following elevated temperatures resulting from fire and therefore address a combined abnormal environment of high thermal followed by shock. An aircraft crash (shock, static loading of the case) followed by fire is a "more credible" order of the combined environments and one for which the firing set response is predictably safe.

There are plans to test the new MC4137 TSSG to combined shock and thermal tests. The steel case (exclusion region) and rolamites were selected based on the threat of combined abnormal environments. The sequence of the thermal and shock should pose no threat to the predictability of the all-steel design.

5. Reliability

Summary

The reliability of the B61-6,8 has been predicted using the methods briefly described in this chapter.

To predict the bomb reliability, a failure analysis is performed for each component. Current assessments are used for the components of the parent weapon or those that are common to the B61-7 or B61-3,4 based upon stockpile data. Predictions for new components are based on all available data from similar components in comparable weapon systems and on data for individual piece parts and their design use.

The command disablement system is to have the following MC-specified reliability and premature probability characteristics:

Conclusions

Delimiting Conditions

The predicted reliability is conditional on the following:

1. Stockpile and use environments will be no more severe than the normal logistical and operational environments described in the STS.
2. All AMAC inputs will be present and proper.
3. There will be no human errors in bomb handling or preparation for use that will reduce its reliability.
4. The bomb and all of its components will be built to the usual DOE standard of production and process control.
5. The specified end-of-life of limited-life components will not be exceeded. Reliability assessments are considered to apply at the end of specified-life for limited-life components.
6. Failure events not treated otherwise are mutually exclusive or statistically independent.

6. Use Control

The B61-6,8 use control features include a command disable system and a Category D PAL System. Additional details about these features are discussed in the Use Control Addendum for the B61-6,8 Bomb (Reference 37).

Command Disable System

Command disablement of the B61-6,8 can be initiated from the aircraft or at the preflight controller (Figure 23) on the bomb.

The disablement system is composed of a DE1002 Coded Device and a MC3246A Thermal Battery.

Disablement results when (1) the correct three-digit disablement code is set on the DE1002 Code Switches, (2) the function select switch is set to the DI (disable) position, and (3) the T-handle is extracted, mechanically initiating the MC3246A battery. The disablement loads located within the bomb center case, each isolated by discreet resistors within the MC4139 Junction Box, are in parallel off the output of the MC3246A battery.

Category D PAL

The B61-6,8 Category D PAL subsystem consists of an MC2907A Multiple Code Coded Switch (MCCS), an MC2946 Output Switch, and a PAL Regulator. When the subsystem is locked, the bomb cannot be prearmed. The PAL subsystem is shown schematically in Figure 47.

MC2907A Multiple Code Coded Switch

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APPENDIX A

Military Characteristics for the B61-6,8 (Proposed)

Military Characteristics	Comments

1. (U) *General*

1.1 (C-FRD) *Purpose*: This portion of the Military Characteristics (MCs) specifies the requirements of the Department of Defense (DOD) to the Department of Energy (DOE) for the B61 Mods 6 and 8 (B61-6,8) gravity bombs. The modifications are to incorporate modern safety, security, and operational features. The B61-6, 8 designs shall have the features delineated in paragraph 2 of these MCs.

1.1.1 (U) The B61 Mod 6 is a modification of the B61 Mod 0.

1.1.2 (U) The B61 Mod 8 is a modification of the B61 Mods 2 and 3.

1.2 (U) *Contingencies*: The design, development, test and evaluation of the bombs will be coordinated by the B61 Project Officers Group (POG). Should it appear impractical to meet any of these characteristics or that meeting them will unduly delay development or production of the bombs, incur unreasonable costs, or require excessive special nuclear materials, prompt notification shall be made by the Lead Project Officer (LPO) via service channels to the Nuclear Weapons Council Standing Committee (NWCSC).

1.3 (U) *Competing Characteristics*: In the event that compliance with these MCs results in design conflict, priorities shall be observed in the order listed below, giving consideration to tradeoffs which allow higher priority MCs to be attained while minimizing the degradation of the competing lower priority MCs. Operational effectiveness, technical feasibility, schedule, and cost will provide the basis for making tradeoffs among the desired competing characteristics. Tradeoffs may be made with the guidance and approval of the B61 POG. The NWCSC must approve all MC changes.

1.3.1 (U) Nuclear Safety
1.3.2 (U) Minimum Intrinsic Radiation
1.3.3 (U) Reliability
1.3.4 (U) Physical Characteristics
1.3.3 (U) Yield
1.3.6 (U) Radioactive Material Dispersal
1.3.7 (U) HE Safety
1.3.8 (U) Economical Use of Nuclear Material
1.3.9 (U) Operational Simplicity
1.3.10 (U) Command and Control Features
1.3.11 (U) Maintenance

2. (U) *Bomb Characteristics*

2.1 (U) *General Considerations:*

2.1.1 (U) The bombs shall not require functional testing in the stockpile.

2.1.2 (U) The bombs shall be designed so that the likelihood of plutonium dispersal in an accident environment is minimized.

[redacted]

Military Characteristics	Comments

2.1.4 (U) Provision shall be made for easy removal of some component of the electrical system vital to the function of the bombs. This provision shall not compromise Service operational requirements or storage criteria. Since this feature is a use-control function only, the bomb must meet all nuclear safety requirements in paragraph 2.8 whether the separable component is installed or removed.

2.1.3 (U) The design of the bomb shall be consistent with the environmental conditions delineated in the stockpile-to-Target Sequence (STS) and shall be deliverable in accordance with aircraft profiles in the STS.

2.2 (U) *Operational Considerations:*

[redacted]

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[redacted]

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2.3.3 (U) Groundburst (Freefall)

2.3.4 (U) Laydown: (Retarded delayed groundburst.) The firing times shall be the same as the parent bomb.

[redacted]

DOE
DoD
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2.3.6 (U) The bombs shall be capable of functioning properly in water depth to the limits of the Laydown timers.

2.4 (U) *Physical Characteristics:*

2.4.1 (U) Weight: 770 pounds (nominal)

2.4.2 (U) The length shall be 141.6 inches maximum.

2.4.3 (U) The body diameter shall be 13.3 inches maximum.

2.4.4 (U) The shape and geometry of the bombs shall be such as to minimize drag and adverse flight characteristics on the strike aircraft during all phases of the flight profile.

2.4.5 (U) War reserve bombs shall be identified with permanent and distinctive markings.

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November 30, 1977

(Excerpted from)

AN EXAMINATION OF THE U. S. NUCLEAR WEAPON INVENTORY

COORDINATION DRAFT
WORK IN PROGRESS

R. N. BRODIE

ATOMIC WEAPON DATA
PRODUCTION AND STOCKPILE INFORMATION

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FY 79: P&PD Plan

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Weapon	Action	Quantity	Priority	Type
B28FI	Interim – Enhanced Electrical Safety Mod [redacted] Replaced by B77 FY82–85		1	Field Retrofit
W25 (Genie)	Change Safety Rules to Prevent Peacetime Loading Use Retired Denuclearized Warheads for Training		1	Factory (Pantex)
B53	Remove from Normal Peacetime Alert		1	Administrative
B61-2	Upgrade to B61-5 Configuration All [redacted]		2	Field Retrofit
W53 (Titan II)	Enhanced Electrical Safety Mod		2	Field Retrofit
W70 (Lance)	[redacted] Mod 0, –1's to –2 Configuration with Enhanced Electrical Safety Mod		2	Factory Rebuild

FY 80: P&PD Plan

Weapon	Action	Quantity	Priority	Type
B28FI	Complete Enhanced Electrical Safety Mod		1	Field Retrofit
W31 (Nike Herc)	[redacted] Enhanced Electrical Safety, MCCS, & Non-Violent Command Disable		1	Field Retrofit
B61-1	[redacted] Include Enhanced Electrical Safety, IHE, MCCS, and Non-Violent Command Disable (B61-X, High Yield)		2	Factory Rebuild
B61-0	[redacted] to B61-X		2	Factory Rebuild
B61-2	Complete Upgrade to B61-5		2	Field Retrofit
W53 (Titan II)	Complete Enhanced Electrical Safety Mod		2	Field Retrofit
W70 (Lance)	Complete Upgrade to W70-2 Configuration With Enhanced Electrical Safety		2	Factory Rebuild

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APPENDIX A

Modernization Program

Recommended Systems (Priority Ordered)	Modifications Desired	Modifications Required	Schedule	Comments
B28FI (Strategic Bomb)	Field retrofit for enhanced electrical safety. Replace HVTB and high voltage arm/safe switch with low voltage transverter power supply and unique signal strong link switch [redacted]		FY81	
W25[1] (GENIE)	Field retrofit for enhanced electrical safety. Replace HVTB with low voltage transverter, redesign arm/safe switch, improve ESD and lightning/EMR immunity features.		FY81	Feasibility and cost of modifications required. Number and schedule dependent on feasibility and future requirements for new air defense system.
W31[1] (HONEST JOHN and NIKE HERCULES)	Field retrofit for enhanced electrical safety and improved command and control. Isolate HVTB inputs		FY81	Resolution of recommended electrical safety improvements required. Planned Army modifications to NH and MCCS should be considered.
B61-0, 2, 5 (Theater Nuclear Bomb)	Factory rebuild to include IHE, EES, CD, CAT D PAL, and unique signal strong link [redacted]		FY83	Schedule dependent on DoE factory capability.
B61-1 (Strategic Bomb)	Factory rebuild to include IHE, EES, CD, CAT D PAL, and unique signal strong link [redacted]		FY83	Schedule dependent on DoE capability. Retrofit should not exceed [redacted]
B54[2]	Field retrofit to provide a unique signal switch to interrupt ferro-electric transducer output.		FY83	Resolution of recommended electrical safety improvements required. Alternate methods of providing enhanced command and control features should be investigated.
B43Y1[1]	Field retrofit for enhanced electrical safety to include unique signal strong link switch [redacted]		FY83	feasibility and cost of modifications required.
B53[1]	Field retrofit for enhanced electrical safety with transverter firing system and unique signal strong link switch [redacted]		FY83	Feasibility and cost of modifications required.
W53[3]	Field retrofit for enhanced electrical safety to include new ESD/power supply/ trigger circuit package.		FY81	Final decision to modify W53 is dependent upon Air Force to determine impact associated with incorporating unique signal capability.

[1]Modification and schedule dependent upon cost and feasibility review.
[2]Resolution of recommended safety improvements required.
[3]Modification and schedule dependent upon Air Force review of incorporating unique signal capability.

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APPENDIX B

Summary of Systems not Recommended for Modernization*

System	Reason
W70 MODs 1, 2, 3	Army feasibility study to consider the alternatives of modernizing the LANCE or replacing it with a follow-on system. Army MENS for a Corps Support Missile System is being drafted.
B57 TAC	Tactical alert requirement to be satisfied by B61s. System should continue to be reviewed.
B57 DB	Navy/DoE ASW Phase 1 Study.
W44 ASROC	Navy/DoE ASW Phase 1 Study.
W55 SUBROC	Navy/DoE ASW Phase 1 Study.
W69 (SRAM)	Air Force Safety Feasibility Review and Air Force/DoE ASALM Phase 2 Study.
W33	Replacement.
W45 (MADM)	Retirement.
W45 TERRIER	Replacement, modification or retirement should continue to be reviewed.
W48	Replacement.
W50	Replacement.
W56, W58, W62, W68, W76, W78	Safety and security such that replacement, modification or retirement should continue to be reviewed.

*Modernization to enhance safety and security for these systems is not recommended at this time due to production/retirement projections and exposure levels. These systems should be reconsidered in conjunction with the periodic review of the ongoing program.

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Sandia National Laboratories
Albuquerque, New Mexico 87185

G. C. Dacy
President

Maj. Gen. William W. Hoover
U.S. Department of Energy
Office of Military Application
Washington, D.C. 20545 (M1382)

Subject: Stockpile Improvement Program (U)

In August 1978, reference 1 recommended nuclear-detonation safety and radioactive-material-scatter safety upgrades for selected stockpiled weapons with high exposure to possible abnormal environments and with potentially troublesome responses to those environments. In April, 1979, with DOD concurrence (Ref. 2), we initiated development activity on the B28FI aimed at providing field retrofit kits to enhance the nuclear-detonation safety of that weapon. Although delayed one year because of production funding problems, the design is now complete. In addition to enhanced nuclear-detonation safety, the refurbished B28FI will incorporate a Category D PAL, improved EMR/EMP resistance, and a "hot drop" feature which requires aircraft power at release. More recently, because of capacitor reliability concerns we and BKC have added a provision to screen returned firing sets at BKC. I understand that BKC expects first kit shipment to the Air Force in April 1983 on schedule.

Development start-up on the W31 was delayed at DOD's request pending the resolution of differences between the DOE proposal and the Army's recommendations (Ref. 2). A joint Army/DOE study was chartered to resolve these differences, and this group provided recommendations to the Army Staff in September 1979. The Army staff responded in October 1980. This apparent lack of interest by the Army coupled with other demands placed on our weapon development activities during the intervening 21 months prior to the receipt of reference 3 have caused us to commit fully our weapon development resources through FY 1982. Following receipt of reference 5, we initiated action to examine ways of reprogramming FY 1982 resources so that W31 development could begin early next fiscal year (FY 1982). This reallocation process has not been completed; consequently, we are unable, at this time, to commit the improved W31 design to a specific date. We expect to complete this reallocation activity within a few months and will provide our schedule assessment at that time.

The B61 improvement which was also agreed to by the DOD (Ref. 2) was started concurrent with the B28FI in April 1979.

Reference 6 provided BKC's assessment of their ability to support the production schedules. It concluded that B61 improvement schedules could be supported provided that needed engineering releases occurred in the approximate time frames identified in the production planning assessment. This assessment called for early engineering releases commencing in April 1981 and continuing through September 1981 for component parts such as semiconductors, castings, connectors, and forgings. Further, releases for subassemblies were required in August 1981 to continue through December 1981. Because of the added features noted above, design maturity and development status did not and do not support the issuance of all releases needed at this time. This factor coupled with heavy demands on Sandia weapon development resources for FY 1982 suggest that a prudent approach would be to slip the B61 Phase 6 FPU by approximately 9 months. We believe this action is necessary to allow for a more orderly and less risky B61 development and production program if the design is to retain the additional features.

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Although we endorse the inclusion of these additional features and believe this design should be pursued on modified timescales, another option still exists which we believe can support the existing schedule.

[redacted]

If support of the existing schedule is considered more important than provisions for these additional features, a decision must be made now while a design alternative still exists that supports the FY84 Phase 6. If we decide to accept a delay in B61-7 Phase 6, I suggest that you consider using that released production capacity to accelerate the build of the additional B61-4's now authorized.

We support and will continue to pursue the present baseline definition with all the features previously mentioned unless you notify us that current schedules must be protected.

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MINUTES OF FINAL

DESIGN REVIEW AND ACCEPTANCE GROUP (DRAAG)

MEETING ON THE

B61 MOD 7 BOMB DESIGN

17 JULY 1985

JOHN M. LEDERER
AIR FORCE WEAPONS LABORATORY
CHAIRMAN B61 MOD 7 DRAAG

JAMES M. MESNARD
AIR FORCE WEAPONS LABORATORY
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NAVAL WEAPONS EVALUATION FACILITY
NAVY MEMBER

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MINUTES OF FINAL

DESIGN REVIEW AND ACCEPTANCE GROUP (DRAAG)

MEETING ON THE

B61 MOD 7 BOMB

HELD AT SANDIA NATIONAL LABORATORIES ALBUQUERQUE

17 JULY 1985

1. (U) Pursuant to the provisions of DOD Instruction 5030.55, "Joint AEC-DOD Nuclear Weapons Development Procedures," 21 January 1974, and AF Regulation 80-9, "Nuclear Weapons Development Procedures," 17 May 1976, a final DRAAG meeting to review the design of the B61 Mod 7 Bomb was held at Sandia National Laboratories, Albuquerque, NM on 17 July 1985.

2. (U) Participants in the review were representatives of the Air Force Weapons Laboratory (representing the Air Force); Naval Weapons Evaluation Facility (representing the Navy); and the Project Manager for Nuclear Munitions, Albuquerque Field Office (representing the Army). Presentations at the meeting were made by Sandia National Laboratories, Albuquerque and Los Alamos National Laboratory. An attendance list and agenda are attached.

3. (U) The design review addressed the B61 Mod 7 design as presented in the Draft Final Development Report (FDR) for the B61 Mod 7 Bomb and the Use Control Addendum for the B61 Mod 7 Bomb, both dated Jun 1985, and compliance by the DOE with the design specifications contained in Ammendment 29, Section II of the B61 Military Characteristics (MCs), 19 November 1984, and the B61 Stockpile-to-Target Sequence (STS), Revision 6 15 April 1984. Fifteen comments from the services and corresponding responses form the DOE laboratories relative to the design were discussed.

A. (U) Items specific to the B61 Mod 7.

(U) The following aspects of the B61 Mod 7 deviate from specifications in the B61 Mod 7 MCs and STS.

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(2) (U) Safety: The probability of a premature nuclear detonation in the normal environments described in the STS shall not exceed: (MC para 2.5.1.3) "After release and prior to fuzing: 1 x 10 per occurrence." (Where "fuzing" is defined as receipt of a fire signal from the radar, timer, or contact crystal, as appropriate) The DOE assesses the probability as 1 x 10 during the period after release and prior to expiration of the safe separation time. The probability of premature nuclear detonation is estimated to be 2 x 10 during the period from safe separation time to fuzing.

(3) (U) STS Environments: The nuclear environments specified in Table 3.14 of the STS for Stage 6 (Release and Free flight) are not adequately defined for testing purposes. The sensitivity of the MC 3637 Programmer and MC 3638 ICU to gamma dose and dose rate has been explored in laboratory tests.

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B. (U) B61 Mod 7 Conclusions:

(U) The B61 Mod 7 design deviations noted in para A above are considered minor and should result in no important impact on SACs planned operational use of the B61 Mod 7.

C. (U) General Items:

(U) In response to the Service Comments on the Draft FDR for the B61 Mod 7, the DOE agreed to include the following items in the Final Development Report.

(1) (U) The operating characteristics of the MC 3640 Trajectory Sensing Signal Generator will be shown, including the no-operate and operate limits.

(2) (U) DOE will expand the description of the MC 3554 Neutron Generator to explain its noise immunity.

(3) (U) The discussion of the Lightning Arrestor Connector will be expanded to show how the MC 2969/2935 Strong Link Switches add to lightning protection. A SNLA report on (LAC/SLS) reliability will be referenced.

(4) (U) An expanded discussion and analyses of credible combined abnormal environments will be included.

(5) (U) The discussion of the T 1563 APC and T 1572 PDM will be combined and expanded.

(6) (U) The FDR will reference specific sections and/or pages relative to compliance with the MCs.

(8) (U) Functional Block Diagrams of the B61 Mod 7 Bomb will be included in the FDR.

4. (U) Recommendations:

A. (U) B61 Mod 7 DRAAG Specific Recommendations:

(1) (U) Exceptions from the design requirements mentioned above be accepted for the B61 Mod 7 Bomb.

(2) (U) Changes to the Draft FDR and FDR Addendum agreed at the DRAAG meeting and listed in C above be published in the final reports.

(3) (U) The B61 Mod 7 be accepted as a standard stockpile item.

B. (U) DRAAG General Recommendations:

(U) The DRAAG did not have approved Military Characteristics at hand, but only verbal assurances of what had been approved by the MLC. The DRAAG cannot function effectively without official written approved MC's and changes. It is recommended no DRAAGs be convened on specific nuclear weapons until approved MC's on those weapons have been made available to the DRAAG members. We also recommend the DRAAG chairman receive information copies of DRAAG related documents (MCs, DRAAG Minutes, Policy guidance, etc) which are forwarded to ATSD(AE) anQ DOE/MA by Service Staffs and ATSD(AE) respectively.

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JOINT DOD/DOE TRIDENT MK4/MK5 REENTRY BODY ALTERNATE WARHEAD PHASE 2 FEASIBILITY STUDY REPORT (U)

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CSA	(U) Canned Subassembly
CTB	(U) Comprehensive Test Ban
CTE	(U) Coefficient of Thermal Expansion
D5	(U) Trident II SLBM
DASMA	(U) Deputy Assistant Secretary for Military Applications
DDRE	(U) Department of Defense, Research ,and Engineering
DGZ	(U) Designated Ground Zero
DIA	(U) Defense Intelligence Agency
DIRSSP	(U) Director, Strategic Systems Programs
DISA	(U) Defense Information Systems Agency
DITWG	(U) Design Integration Technical Working Group
DoD	(U) Department of Defense
DOE	(U) Department of Energy
DNA	(U) Defense Nuclear Agency
DSA	(U) Dual Stronglink Assembly
DSSL	(U) Detonator Safing Stronglink
D-T	(U) Deuterium - Tritium
EAM	(U) Emergency Action Message
ECA	(U) Electronic Component Assembly
EHW	(U) Explosives Handling Wharf
EMP	(U) Electromagnetic Pulse
EMR	(U) Electromagnetic Radiation
ENDS	(U) Enhanced Nuclear Detonation Safety
EOL	(U) End Of Lifetime
EPOT	(U) Enclosure for the Protection of Ordnance in Transit
ESD	(U) Environmental Sensing Device
ESSD	(U) Environment Sensing Signal generating Device
ESSG	(U) Environmental Sensing Signal Generator
FARR	(U) Fail-safe and Risk Reduction Study
FBIA	(U) Force-Balancing Integrating Accelerometer
FBM	(U) Fleet Ballistic Missile
FEM	(U) Finite Element Model
FOM	(U) Figures of Merit
FONSI	(U) Finding of No Significant Impact
FOUO	(U) For Official Use Only
FPU	(U) First Production Unit

FRD	(U) Formerly Restricted Data
FRC	(U) Fire-Resistant Capsule
FRE	(U) Fire-Resistant Enhancement
FRP	(U) Fire-Resistant Pit
GLCM	(U) Ground-Launched Cruise Missile
GTS	(U) Gas Transfer System
HASC	(U) House Armed Services Committee
HERO	(U) Hazards of Electromagnetic Radiation to Ordnance
HMX	(U) Prime ingredient in a high explosive (Cyclotetamethylenetetronitramine)
HOB	(U) Height of Burst
ICBM	(U) Intercontinental Ballistic Missile
ICD	(U) Interface Control Drawing
IEMP	(U) Internal Electromagnetic Pulse
IFD	(U) In-Flight Disconnect
IH	(U) Inert Head
IHE	(U) Insensitive High Explosive
IND	(U) Inadvertent Nuclear Detonation
INRAD	(U) Intrinsic Radiation
IOC	(U) Initial Operational Capability
JCS	(U) Joint Chiefs of Staff
JTA	(U) Joint Test Assembly
LAC	(U) Lightning Arrestor Connector
LAE	(U) Large Accurate Evader
LANL	(U) Los Alamos National Laboratory
LANT OP	(U) Atlantic Operations
LIHE	(U) Light-Initiated High Explosive
LL	(U) Lower Left
LLC	(U) Limited-Life Component
LLCE	(U) Limited-Life Component Exchange
LLNL	(U) Lawrence Livermore National Laboratory
LMSC	(U) Lockheed Missiles and Space Company
MaRB	(U) Maneuvering Reentry Body
MARV	(U) Maneuvering Reentry Vehicle
MAST	(U) Multi Application Surety Technology
MCs	(U) Military Characteristics

MIRV	(U)	Multiple Independently-Targetable Reentry Vehicle
MK4	(U)	Mark 4 Reentry Body
MK5	(U)	Mark 5 Reentry Body
MK12	(U)	Mark 12 Reentry Vehicle
MK12A	(U)	Mark 12A Reentry Vehicle
MK21	(U)	Mark 21 Reentry Vehicle
MLC	(U)	Military Liaison Committee
MOE	(U)	Measures of Effectiveness
MOI	(U)	Moments of Inertia
MSAD	(U)	Mechanical Safe and Arm Detonator
N/F	(U)	Nose Fairing
NASA	(U)	National Aeronautics and Space Administration
NCCS	(U)	Nuclear Command and Control System
NEP	(U)	Nuclear Explosive Package
NG	(U)	Neutron Generator
NM	(U)	New Mexico
NORC	(U)	Nuclear Ordnance Record Card
NSA	(U)	US National Security Agency
NTB	(U)	National Target Base
NTS	(U)	Nevada Test Site
NWC	(U)	Nuclear Weapons Council
NWCSC	(U)	Nuclear Weapon Council Standing Committee
NWCWSC	(U)	Nuclear Weapons Council Weapons Safety Committee
NWEF	(U)	Naval Weapons Evaluation Facility
NWWG	(U)	New Warhead Working Group
OASD/ISP	(U)	Office of the Assistant Secretary of Defense/International Security Policy
OSD/ISP	(U)	Office of the Secretary of Defense/International Security Policy
Oy	(U)	Oralloy
PAC OP	(U)	Pacific Operations
PAL	(U)	Permissive Action Link
PASS	(U)	Pre-production Accelerated Stockpile Surveillance
PBV	(U)	Post-Boost Vehicle
PBCS	(U)	Post-Boost Control System
PEIS	(U)	Programmatic Environmental Impact Statement
PETN	(U)	Pentaerythritol Tetranitrate

PEX	(U) Paste Extrudable Explosive
PIGMA	(U) Pressurized Inert Gas Metal Arc
PINEX	(U) Pinhole Experiment (Neutron Imaging Pinhole Camera)
PK	(U) Probability of Kill
POC	(U) Probability of Clearance
POG	(U) Project Officers' Group
PRESS	(U) Pit Reuse for Enhanced Safety and Surety
PRP	(U) Personnel Reliability Program
R&D	(U) Research and Development
R/E	(U) Reentry
RA	(U) Release Assembly
RB	(U) Reentry Body
RBA	(U) Reentry Body Assembly (RB mounted on Release Assembly)
RBC	(U) Reentry Body Complex
RBM	(U) Reentry Body Magazine
RD	(U) Restricted Data
RDT & E	(U) Research, Development, Test, and Evaluation
REB	(U) Reentry Body Building
RF	(U) Radio Frequency
RFP	(U) Rocky Flats Plant
ROM	(U) Read Only Memory
ROMA	(U) Relative Overall Merit Assessment
RS	(U) Reentry System (includes WH, RB, AF&F, RA)
RUPL	(U) Radar-Updated Path Length
RV	(U) Reentry Vehicle
S	(U) Secret
SAFEPOT	(U) Small Arms Fire Enclosure for the Protection of Ordnance in Transit
SALAD	(U) Slide Armed Laser Actuated Device
SAS	(U) Sealed Authentication System
SASC	(U) Senate Armed Services Committee
SECDEF	(U) Secretary of Defense
SECNAV	(U) Secretary of Navy
SFRD	(U) Secret Formerly Restricted Data
SGEMP	(U) System-Generated Electromagnetic Pulse
SGT	(U) Safeguards Trailer

SHOB	(U)	Scaled Heights of Burst
SLBM	(U)	Submarine Launched Ballistic Missile
S.M.	(U)	Static Margin
SNL	(U)	Sandia National Laboratories
SNL/CA	(U)	Sandia National Laboratories/California
SNL/NM	(U)	Sandia National Laboratories/New Mexico
SNM	(U)	Special Nuclear Material
SOA	(U)	Speed of Advance
SPETWG	(U)	Systems Performance and Effectiveness Technical Working Group
SRAM	(U)	Short Range Attack Missile
SRD	(U)	Secret Restricted Data
SRD/N	(U)	SRD/CNWDI
SSBN	(U)	Submersible Ship, Ballistic, Nuclear
SSE	(U)	Surface Support Equipment
SSNT	(U)	Shape Stable Nosetip
SSP	(U)	Strategic Systems Programs
SSPK	(U)	Single Shot Probability of Kill
SST	(U)	Safe, Secure Trailer
SSU	(U)	Separation Sequencer Unit
START	(U)	Strategic Arms Reduction Treaty
STAS	(U)	Safe-to-Arm Signal
STRATCOM	(U)	Strategic Command
STS	(U)	Stockpile-to-Target Sequence
STWG	(U)	Steering Task Working Group
SU	(U)	Service Unit
SWF	(U)	Strategic Weapons Facility
SWFLANT	(U)	SWF, Atlantic (Kings Bay, GA)
SWFPAC	(U)	SWF, Pacific (Bangor, WA)
SWOP	(U)	Special Weapons Ordnance Publication

[redacted]

b(3)

DOE

[redacted]

b(3)

[redacted]

DOE

U	(U) Unclassified
UC	(U) Use Control
UGT	(U) Underground Test (Nuclear)
UK	(U) United Kingdom
UL	(U) Upper Left
UM	(U) Upper Middle
UQS	(U) Unique Signal
UR	(U) Upper Right
USN	(U) United States Navy
V&H	(U) Vulnerability and Hardening
V-γ	(U) Reentry Velocity-Gamma (Flight Path Angle)
VNTK	(U) Target Vulnerability Number
WESVA	(U) Weapon Safety Value Assessment
WG	(U) Working Group
WH	(U) Warhead
WR	(U) War Reserve
WSR	(U) Weapon System Reliability
Z	(U) Atomic Number

10. Homsy, R.V., et al, "Weapon Safety Value Assessment (WESVA): A Decision Aid for Comparing Warhead Advanced Surety Designs," Lawrence Livermore National Laboratory, Livermore, CA, UCRL to be published 1994.

11. "Relative Overall Merit Assessment (ROMA), " Los Alamos National Laboratory, Los Alamos, NM, report to be published 1994.

SLBM PHASE 2 STUDY
EXECUTIVE SUMMARY

(U) The SLBM Phase 2 Study was conducted to identify and quantify alternatives to the W76/MK4 and W88/MK5 reentry systems. The study was in response to increased emphasis on safety, the limited production capability of the DOE complex, and the expected extremely long service life of the enduring stockpile. The alternatives were evaluated with respect to the following attributes:

Enhanced weapon system safety
Desensitization to aging effects
Minimum need for refit
Reliability
Compatibility with existing DoD/DOE hardware
Security and use control
Reduced dependence on nuclear testing
Producibility
Effectiveness

b(3)

(CRD) A broad range of MK5A candidates has been proposed.

One candidate offers a safety capsule enveloping a W76 NEP and there are three all-Oy (Oralloy) designs, which contain no plutonium. Most MK5A alternatives incorporate ENDS (Enhanced Nuclear Detonation Safety), e.g., advanced detonator safing, and robust exclusion barriers, IHE (Insensitive High Explosive), FRP (Fire Resistant Pits), and devices for use control and denial.

b(3)

DOE

Since the TRIDENT II accuracy is better than its original objective, several MK5A candidates provide effectiveness that is greater than the W88/MK5 at its original accuracy objective.

1. (U) INTRODUCTION AND OBJECTIVES

(U) The purpose of this study was to identify and quantify alternatives to the W76/MK4 and W88/MK5 for use on the TRIDENT weapons systems. These alternatives have been designated MK4A and MK5A throughout this report. While there are no presently identified deficiencies in performance, safety or service life, current strategic force planning will keep MK4 and MK5 in the deployed inventory for an extremely long time and therefore decreased sensitivity to aging was emphasized. Also stressed were enhanced safety, system reliability, decreased need for underground tests (UGT), and flexibility in meeting future requirements. Warhead yield was de-emphasized in favor of other attributes. A goal was to maximize the use of existing DoD hardware in order to minimize system costs.

[redacted] b(3) DOE

(U) Based on the above broad guidance, the study ground rules included no changes to the D5 or C4 missile system hardware or to missile-to-RBA (Reentry Body Assembly) interfaces. External MK4 and MK5 aeroshells, including nosetip and heatshield, were to be unchanged. Changes to the MK4 AF&F (Arming Fuzing & Firing System) were allowable to enhance reliability and safety. System mass properties were kept as close as possible to MK4 and MK5 values to preserve the flight test and accuracy database, and minimal change to existing Stockpile-to-Target Sequence (STS) normal, abnormal and hostile environments was desired.

(SFRD) Draft Military Characteristics (MCs) for the WXX/MK5A and WYY/MK4A increased emphasis on modern safety features and on the potential for minimizing plutonium dispersal. b(3)

[redacted] DOE, DTRA

Intrinsic radiation levels are TBD, but as low as possible (Reference 4).

(U) The study was conducted by the SLBM Phase 2 Study Group, which was formed from the W88/MK5 Project Officers Group, with the addition of the LLNL/Sandia team as study members. Observers included DOE/Headquarters, ATSD(AE) and

CNO(N514). DoD/DOE reentry concepts were developed and evaluated by technical working groups, including Design Integration, Safety, Vulnerability, Joint Test, Quality and Reliability, Logistics and Production, Fail-Safe and Risk Reduction, and Systems Performance and Effectiveness. An additional working group developed draft Military Characteristics and preliminary Stockpile-to-Target Sequences (References 4, 5 and 6).

2. (U) BACKGROUND INFORMATION

(U) In recent years, the character of the US strategic deterrent has been changing. The total US strategic inventory has been reduced by START I and II agreements, and this has increased emphasis on the SLBM force. Nuclear weapon safety has received additional attention from policy makers, with desire for increased margins, while a stringent budget climate has reduced funding for weapons-related activities. b(3) DOE

(SFRD) The MK4 and MK5 TRIDENT reentry systems meet all goals and standards, and there are presently no identified deficiencies in performance, safety or service life. b(3) DOE

b(1) DTRA

(U) On 26 March 1992, the Director of Strategic Systems Programs (SSP) initiated a formal request to the Chairman of the Nuclear Weapons Council Standing Committee (NWCSC) for a joint DoD/DOE Phase 2 Study to identify and quantify alternatives to the W76/MK4 and W88/MK5 to increase service life and increase safety margins (Reference 1). Since the alternatives would not modify existing delivery systems, a Phase 1 study was not conducted.

(U) On 27 April 1992, the Chairman, NWCSC, requested the DOE to join with the DoD in Phase 2 activities (Reference 2). IOC for the replacements would be in the late 1990's and the quantity would be sufficient to replace the existing W76/MK4 and W88/MK5 systems.

(U) The DOE(DASMA) responded to the NWCSC request on 29 April 1992 and accepted the request for a Joint DoD/DOE Phase 2 Study (Reference 3).

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(U) The SLBM Phase 2 Study schedule is shown in Figure 2-1. The kickoff meeting was held in June 1992 and Study Group Meetings were held approximately every six weeks. Interface definitions and requirements were developed early in the study and the DOE identified preliminary warhead concepts. Candidate warheads and associated DOE hardware were integrated into DoD-produced MK5 and MK4 hardware by a joint DoD and DOE team. Evaluation of the MK5A and MK4A candidates was done throughout the study. A DOE Peer Review, including detailed nuclear safety and performance calculations, was conducted late in the Study and will be reported separately. The SLBM Phase 2 Study was completed in January 1994 with the issuance of the final report.

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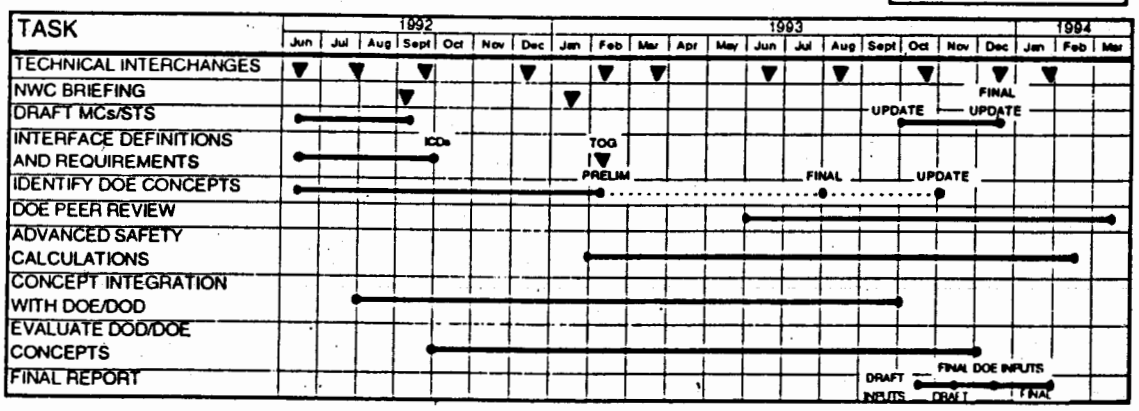


FIGURE 2-1
(U) SLBM PHASE 2 STUDY SCHEDULE

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SECRET FORMERLY RESTRICTED DATA

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3.3 (U) REPORT OF THE HASC PANEL ON NUCLEAR WEAPONS SAFETY

The following section is an extract from the executive summary of the House Armed Services Panel Report, commonly known as the Drell Report. It is included here because of its relevance to the SLBM Phase 2 Study.

(U) Concerns that have been raised recently about the safety of several of the nuclear weapons systems in the U.S. arsenal have led the government to take immediate steps to reduce the risk of unintended, accidental detonations that could result in dispersing plutonium into the environment in potentially dangerous amounts, or even generate a nuclear yield. These steps include temporarily removing the short-range air-to-ground attack missiles, SRAM-A, from the alert bombers of the Strategic Air Command and modifying some of the artillery-fired atomic projectiles (AFAPs) deployed with U.S. Forces. In addition, the Departments of Defense and of Energy, which hold dual responsibility for the surety of the U.S. stockpile of nuclear weapons systems--i.e., for their safety, their security, and their control--have initiated studies looking more broadly into safety issues.

(U) This is a very important, as well as opportune, moment to undertake a safety review of nuclear weapons for reasons that go well beyond the immediate concerns of several specific weapons. As we enter the last decade of the 20th century, the world is in the midst of profound, and indeed revolutionary, changes in the strategic, political, and military dimensions of international security. These changes, together with a continuing rapid pace of technical advances, create an entirely new context for making choices in the development of our nuclear forces for the future. It is likely that, in the future, the U.S. nuclear weapons complex will evolve into a new configuration--perhaps smaller and less diverse and at lower operating expense but with enhanced requirements for safety and control.

(U) In this report we propose organizational initiatives to strengthen and make more fully accountable the safety assurance process, and we identify priority goals for enhancing safety in a timely fashion. We

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emphasize the importance of developing the data bases and performing credible safety analyses to support weapons design choices. We also affirm the importance of vigorous R&D efforts in the DOE weapons laboratories in search of new technologies leading to significant advances in safety-optimized designs.

(U) The starting point of our study is provided by two recent analyses which included inquiries into the nuclear weapons safety process: The 1985 President's Blue Ribbon Task Group on Nuclear Weapons Program Management, chaired by Judge William T. Clark, and the 1988 DOE Nuclear Weapons Safety Review Group, chaired by Gordon Moe. Both of these panels addressed long-standing concerns with stockpile safety and made important recommendations, a number of which were implemented, including in particular creation of a Nuclear Weapons Council (NWC) and an NWC Weapon Safety Committee. It is our present finding that although many problems have been, or are being, fixed, still more remain to be addressed. We are concerned, as were these earlier panels, that serious issues that had been known for at least a decade remained unattended for so many years.

(U) We make seven major recommendations for strengthening the safety assurance process. They should be implemented promptly and effectively.

(U) 1. Create joint DoD/DOE dedicated "Red Teams" with the important responsibility to scrutinize and challenge the weapons designs and operational procedures for each nuclear weapons system remaining in the stockpile or under development. The Red Teams would normally interact directly with the Weapons Design Teams. However, in case of unresolvable differences of views on safety issues, the Red Teams would have direct channels up the line of authority to the Nuclear Weapons Council and to the Secretaries of Defense and Energy if necessary.

(U) 2. Create a Joint Advisory Committee for Nuclear Weapons Surety which would report directly to the two Secretaries of Defense and

Energy. This committee would be responsible for examining ongoing practices in both DoD and DOE with respect to nuclear weapon surety, would have oversight of the surety reviews conducted on specific systems, and would identify and inform the Secretaries of any serious surety issue and provide advice as to the appropriate response.

(U) Together with the Red Teams, the Joint Advisory Committee will provide confidence that all surety issues and requirements for the U.S. stockpile are identified, given a thorough technical analysis, and addressed in a timely fashion.

(U) 3. Strengthen and more tightly focus the responsibilities of the two offices charged with managing nuclear weapons issues within the Departments of Defense and Energy. Within Defense this is the Office of the Assistant to the Secretary of Defense for Atomic Energy [ATSD(AE)]; and, in Energy it is the Office of the Assistant Secretary for Defense Programs (ASDP). To be effective the charters of both of these offices must clearly delineate their responsibilities and assure their direct access to their respective Secretaries on critical and dangerous issues of nuclear weapons system surety. In particular, the ATSD(AE) should be given a more senior status as a member of the Nuclear Weapons Council (NWC) and upgraded to the same status as an Assistant Secretary of Defense, with a direct line of reporting to the Secretary.

(U) 4. The Deputy Assistant Secretary for Military Applications (DASMA), who plays a crucial role within the DOE Office of the ASDP and also chairs the Nuclear Weapons Council Weapons Safety Committee (NWCWSC), currently is required to be a flag-rank officer on active military duty. We recommend that the occupant of this position be chosen as the most qualified individual--civilian or military.

(U) 5. Designate the Assistant Secretary for Defense Programs (ASDP) in DOE as chairman of the Nuclear Weapons Council, whose other two members are from Defense (the DDRE and the Vice Chairman of the

(U) The primary goal of these seven recommendations is to establish a process for safety assurance that is pro-active, effective, and vigilant in search of the desired balance between maximum safety and reasonable military requirements.

(U) Our four major recommendations for enhancing the safety of nuclear weapons systems by reducing the risks of an unintended, accidental, or unauthorized nuclear detonation or dispersal of plutonium apply both to the warheads themselves and to the entire weapon system. For the warheads they imply design choices for the nuclear components, the high explosives, and the electrical arming system. For the weapons system--i.e., the rocket motors to which the warhead is mated in a missile and the aircraft or transporter that serves as the launcher--safety implies choices of propellants and operational procedures as well as system designs.

(U) 1. Adopt and implement as national policy the following priority goals for improving the safety of the nuclear weapons systems in the stockpile, using available technology:

(U) • equip *all weapons* in the stockpile with modern enhanced nuclear detonation safety (ENDS) systems.

(U) • build *all nuclear bombs loaded onto aircraft*---both bombs and cruise missiles--with insensitive high explosives (IHE) and fire-resistant pits. These are the two most critical safety features currently available for avoiding plutonium dispersal in the event of aircraft fires or crashes.

(U) There are no technical reasons for the DoD and DOE to delay accomplishing these safety goals for existing stockpile weapons; they should be given higher priority than they currently receive.

(U) 2. Undertake an immediate national policy review of the acceptability of retaining *missile systems* in the arsenal without IHE or fire-resistant pits in their nuclear warheads and without using a safer

safety levels before proceeding with new weapons developments. Provide the resources necessary to support this work.

(U) 4. Affirm enhanced safety as the top priority goal of the U.S. nuclear weapons program and direct and appropriately fund DOE weapons laboratories, in fulfilling their national responsibilities, to vigorously pursue R&D in search of new technologies that could create new possibilities for significant advances in safety-optimized designs.

(U) In a classified section of this report we discuss individual weapons systems and the safety concerns arising from the technology they incorporate and the handling and deployment procedures they experience. Finally we discuss improvements or changes that would enhance their safety.

(U) To accomplish the goals we have set out in this study the U.S. nuclear weapons program will have to give higher priority and devote more of its resources to efforts to enhance safety--taking a long-range view in search of big advances in technology beyond just evolutionary, incremental improvements. Such a call for reorienting the emphasis of the current program should not be viewed as requiring an enlargement of the total program particularly as we look forward to maintaining a smaller nuclear force in the new strategic environment. It does however require that adequate and steady resources be made available for the RDT&E needed to underpin such a program.

3.4 (U) FARR BACKGROUND

(U) As a result of a formal request by the Senate Armed Services Committee, the Federal Advisory Committee on Nuclear Fail-safe and Risk Reduction (FARR) was chartered on December 20, 1990 by Secretary of Defense Richard Cheney. The FARR Committee assessed the current and programmed capability of the U.S. Nuclear Command and Control Systems (NCCS) to meet the dual requirements of assurance against unauthorized use and the assurance of timely authorized use, when directed by the President. They also identified opportunities for enhancement of these capabilities. The FARR Committee was tasked to explore the desirability and

feasibility of placing coded control devices in U.S. nuclear weapons at sea. The FARR Committee concluded that enhancements which would further improve the safety, security and control of U.S. nuclear weapons are both feasible and desirable. These conclusions were accepted by Secretary Cheney. Through appropriate channels, the TRIDENT Phase 2 Study Group was tasked to investigate appropriate FARR Committee recommendations for applicability and possible implementation. This is discussed in Section 10.2.

3.5 (U) DOE PRODUCTION CAPABILITY

3.5.1 (U) OBJECTIVE

(U) The Department of Energy (DOE) Production Capability section of this study was requested for the purpose of evaluating the impact on production timelines and capacity by the recently mandated DOE plant reconfiguration project.

3.5.2 (U) SUMMARY

(U) The DOE reconfiguration project consists basically of two major elements:

1. Non-nuclear Production activity; and

2. Nuclear Production activity.

(U) Hazel O'Leary, Secretary of Energy, announced May 27, 1993, that the DOE will proceed with the consolidation of its non-nuclear operations based on information from three independent consultants indicating the non-nuclear plan was cost effective and should be implemented. The nuclear reconfiguration project was basically driven by the "shutdown" of plutonium pit fabrication activity at the Rocky Flats Plant (RFP) near Golden, Colorado by the previous Secretary of Energy Admiral James D. Watkins, USN (Retired).

(U) The non-nuclear reconfiguration project was issued a Finding of No Significant Impact (FONSI) in late September 1993, one month after the scheduled date. Implementation of plans to notify facilities at the four receiver sites began October 1993. The RFP, Pinellas, and Mound donor plants will have equipment,

documentation, and people transferred to the Kansas City, Los Alamos National Laboratory (LANL), Sandia National Laboratories, and Savannah River receiver sites. The last activity transfer (neutron generators) is scheduled to be completed October 1999.

(U) The nuclear reconfiguration project has proceeded through a public comment and scoping period at the various receiver candidate sites during the July - September 1993 period. After appropriate revisions to the implementation plan and drafting a Programmatic Environmental Impact Statement (PEIS), there will be another public comment and hearing period from January - March 1994. A final PEIS is scheduled by August 1994, and a decision by the DOE Secretary whether or not to proceed with the nuclear reconfiguration plan is scheduled in the September - December 1994 time frame.

(U) First Production Unit (FPU) delivery dates for all candidates were assessed based on the DOE reconfiguration schedule and basic guidelines. Candidate FPU delivery dates were analyzed in three time frames:

1. Less than five years;

2. Five to ten years; and

3. Greater than ten years.

(U) A basic DOE guideline is that pit reuse facilities would not be operational in less than five years, and plutonium (Pu) fabrication facilities would not be available within ten years.

(U) In conclusion, the FPU for all candidates is projected to be five or more years after an assumed Phase 3 beginning fourth quarter of FY94. The planned Pantex pit reuse facility is expected to have a capacity of 10 pits per month per shift, expandable to 20 if necessary, which raises concerns for producing an Initial Operational Capability (IOC) quantity by the end of 1999 for those candidates requiring this facility.

3.5.3 (U) BASIC GUIDELINES & GROUND RULES

A. (U) Assumes Phase 3 start fourth quarter FY94.

B. (U) Years to component FPU based on Phase 3 start date.

- Phase 3 delay would shorten time to FPU for mid and far-term in Tables 3.5-1 and 3.5-2.

2. (U) The RFP production contingency mission was removed by DOE several months ago. The DOE Revised Notice of Intent and Programmatic Environmental Impact Statement for Complex-21 are very emphatic that RFP will no longer be able to fabricate Pu pits. Complex-21 will not be available to fabricate new pits until many years after FPU for SLBM. LANL and LLNL both have a capability to fabricate a small number of Pu test articles, but by no stretch of the imagination could this be considered a production capability. b(3) [redacted] DOE

3. (U) The Y-12 plant is currently at a semi-production level of capability and has a production capacity higher than the capability envisioned for the Pantex pit reuse program. If Y-12 were given the budget and programmatic requirement basis within the next few years, it could fabricate all Oy pits on a production basis within three years of notice to do so. Y-12 anticipates substantial budget reductions starting in FY95. If after the budget cuts, Y-12 is able to sustain a minimum capability, it could still begin Oy pit production within three years notice to do so. If the budget cuts reduce Y-12 to a storage-only mode, then five or more years advance notice would be required before Y-12 could start production of an all Oy pit. The year FY95 is a key decision date if the SLBM will use an all Oy pit and if its current production schedule is to be met. b(3) [redacted] DOE

For the CSAs or other Y-12 products required for a complete NEP, Y-12 would be able to meet production requirements subject to the same caveats given in the previous paragraph.

5.1.4.2 (U) W76 Warhead in Safety Capsule (LA5-2)

(CFRD) The W76 warhead inside a custom-designed protective envelope in the MK5 RB is a low cost, maximum reuse proposal that approaches nuclear weapon safety from a different perspective. While significant advances were made in the b(3) DTRA

5.1.4.2.1 (U) *Nuclear System Performance Record*

(U) The safety capsule has been designed to minimize the impact of the safety features upon the proven nuclear performance of the W76 weapon. The material nearest the case is insulating foam which is close to the density of the foam used to mount the W76 warhead in the MK4 RB. Thus the safety capsule is expected to have minimum perturbation on the normal function of the W76 NEP. Indeed the foam fully surrounding the case may even improve radiation case integrity.

(U) In order to demonstrate the viability of the nuclear system when surrounded by different materials than were used in the nuclear tests, an extensive local test program will be pursued. Hydrodynamic tests (hydros) of the baseline W76 will be

compared to hydros of the W76 in the safety capsule. [redacted] b(3) DOE, DTRA

(CFRD) The W76 nuclear system is one of the most completely tested systems in the enduring stockpile. [redacted] b(3) CG-W-5 710 DOE, DTRA

The tests pertinent to this proposal are shown in Table 5.1-4. [redacted] TG-NAS-2 801 DOE, DTRA b(3)

5.1.4.4.8 (U) *Electrical Support System Options, LA5-9*

(U) CAT-E PAL and detonator enabling/safing systems are included in LA5-9. Electrical support systems drawings that follow (Figures 5.1-17 and 5.1-18) are identical, except for detonator and neutron generator designator locations, to those systems described for LA5-4, -6, and -7. New detonator and neutron generator cables are required because of warhead orientation within the RB.

5.1.4.5 (U) All Oy Design (LA5-5)

(U) The usual approach to reducing the hazard of Pu scatter is to reduce the hazard of detonating the HE around Pu bearing pits. Building a pit that does not use Pu is another approach. Oy is an alternative nuclear material that poses a much lower hazard than Pu. This hazard reduction is several orders of magnitude, even after considering that more material is required to achieve a nuclear yield.

(U) FIGURE 5.1-17

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The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE. The connector on the aft closure will require RF and thermal protection. Other than the addition of the connector on the aft closure its design remains very similar to the W88/MK5. Candidate mass properties (RB weight and CG location) are shown in Figure 6.2-2.

(U) This design provides compatibility with the DoD hardware including the AF&F. The proposed CAT-E PAL use control capability is feasible and the concept is compatible with all the missile physical and functional interfaces. The concept has good aerodynamic stability margins.

6.4.3.2 (U) LL5-3a Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The approach used to assess the LL5-3a concept was to compare the design attributes of the forward wedge support area and the aft warhead support to designs that have already been assessed. (See Figure 6.4.3-1). The LL5-3a concept has an aft warhead support design that is similar to the LA5-6 design but with a thicker attachment flange, and a forward warhead support wedge that is structurally the same as the LL5-1 wedge. Both the LL5-1 and LA5-6 designs were extensively analyzed by finite element models. Since the aft warhead support and wedge area were the same or similar to the above mentioned designs, an engineering judgment was made as to the feasibility of the LL5-3a design. The seal cover has a

double curved design similar to the LL5-1 and was assessed based on that design. (See Figure 6.4.3-1). The warhead attachment, the wedge, and the seal cover designs were assessed for the three critical MK5 V–γ trajectories (upper middle-UM, upper left-UL, and upper right-UR) by comparison.

(U) Assessment Results

(U) The assessment of the LL5-3a aft warhead support, the forward wedge support area and the seal cover has margins equal to or greater than the W88/MK5 design based on engineering judgment.

6.4.3.3 (U) LL5-3a Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

(U) The candidate utilizes a foam sleeve similar to that used in the LL5-1 design and employs a bond material similar to that of LL5-1 as well. These configurations were assessed as feasible based on MK5 and LLNL UGT test experience.

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(U) Structural Vulnerability Assessment

(U) For the LL5-3a the high-frequency response effects were only investigated for the substrate stress response in the vicinity of the aft support under side-on impulse loading. This approach was taken because evaluation of a similar design (LL5-1) had indicated that the impulse loading imposed the largest stress on the candidate.

(U) A DYNA3D finite element model was developed to predict the local stress response in this vicinity. The results showed that the peak stresses developed at

critical points in the substrate and in the connecting bolts and bracket were below the corresponding material allowable (i.e., yield strengths).

(U) With regard to low-frequency responses, only blast loading was analyzed since it had been identified as imposing larger stresses than cold or hot X-ray loadings. The approach to assess blast response is illustrated by the flow diagram of Figure 6.4.3-5. The centerpiece of the analysis is the low-order full-body model dynamic analysis. The required warhead forward and aft support stiffness data were determined from separate DIAL finite element analyses. The required warhead spring and mass constants were calculated using the stiffness and mass distribution information supplied from LLNL.

(U) The low-order blast analysis provided the general stress, internal forces/ moments and deflection responses. However, the local stresses (including shell bending effects) at the new warhead support junctions were not calculated. These responses were calculated using the DIAL finite element local support models where the boundary loads were the internal forces and moments obtained from the low-order analysis.

(U) The results showed that the most critical responses occurred in the vicinity of the aft warhead support (Figure 6.4.3-4). The highest stress, 42 ksi, occurred at the substrate inside surface located at the forward edge of the aft support on the hit side. This stress was below the static material (aluminum) yield strength of 49 ksi, at 200° F and was therefore assessed as acceptable.

(U) The DOE/DoD component relative deflection responses at potential physical impact locations indicated that the relative lateral deflections between the chimney and the aeroshell substrate was most critical similar to LL5-1. The potential for impact between the chimney and the aeroshell can be eliminated by increasing the gap between the two components. This was accomplished for the LL5-1 design, and has now been accomplished for the LL5-3a design.

FIGURE 6.4.3-5

(U) BLAST ANALYSIS APPROACH

6.4.4.3 (U) LL5-3b Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

(U) The LL5-3b design has a new foam sleeve design with a bond similar to that of candidate LL5-1 which was assessed to be feasible based on MK5 and MK21/W87 UGT experience.

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(U) Structural Vulnerability Assessment

(U) For high-frequency responses only the substrate stress response in the vicinity of the aft warhead mount, under side-on impulse loading was examined because evaluations made on similar designs (LL5-1 and LL5-3a) have indicated that this condition produces the maximum stress.

(U) In addition, because of their design similarities the high frequency response of LL5-3b was evaluated as being bounded by the responses of LL5-3a and LL5-1 (Figure 6.4.4-2). Therefore, since the high frequency stresses for both LL5-3a and LL5-1 were below material yield limits, the LL5-3b candidate was also expected to have positive high frequency response margin.

(U) Relative to low-frequency responses only the blast loading was analyzed since it is more critical than cold and hot X-ray loadings. The approach to assess blast response is illustrated by the flow diagram of Figure 6.4.3-5.

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(U) This design provides compatibility with the DoD hardware including the AF&F. The proposed CAT-E PAL use control capability is feasible and the concept is compatible with all the missile physical and functional interfaces. The concept has good aerodynamic stability margins.

6.4.7.2 (U) LL5-4c Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The approach used to assess the LL5-4c concept was predicated on the design attributes of the forward warhead support wedge and the aft warhead support. (See Figure 6.4.7-1). This design is very similar to LL5-4a except the weight is 10% greater and the center of gravity is more forward. The LL5-4c concept had an aft warhead support design that is similar to the MK5 IH design, and a forward warhead support wedge that is somewhat larger but is located slightly further aft than the W88/MK5 wedge. Since these two pieces of structure were similar to the MK5 tactical design, the MK5 capability curves were used to determine the feasibility of the design. A parametric study of the MK5 tactical nub concept versus the MK5 IH bolted concept established a set of knock-down factors that were used on this assessment to adjust for the difference in stresses between the MK5 tactical and the MK5 IH designs. The seal cover has a double curved design similar to the LL5-1 and was assessed based on that design. (See Figure 6.4.7-1). The warhead attachment, the wedge, and the seal cover designs were assessed for the three critical MK5 V–γ trajectories (upper middle-UM, upper left-UL, and upper right-UR).

(U) Assessment Results

(U) The assessment of the LL5-4c aft warhead support design reflected margins slightly more negative for the aft warhead flange tapers than the W88/MK5 design. The wedge concept has positive margins of safety. The seal cover design has positive margins both for stress and buckling based on the LL5-1 Assessment.

6.4.7.3 (U) LL5-4c Hostile Reentry Structural Assessment

(U) Because LL5-4a and LL5-4c have identical designs except for warhead internal

mass distribution, the vulnerability responses were expected to be the same except for possible differences in their low-frequency responses. These differences are noted below.

(U) Material Vulnerability Assessment

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(U) Structural Vulnerability Assessment

(U) High-frequency responses for the LL5-4c candidate were investigated for side-on impulse loading only. And only the substrate stress response in the vicinity of the aft support under this side-on impulse loading was examined because evaluation of a similar design (LL5-1) indicated that the impulse loading imposed the largest stress on the hardware.

(U) A DYNA3D finite element model was developed to predict the local stress response in this vicinity. The results showed that the peak stresses developed at critical points in the substrate and in the connecting bolts and bracket were below the corresponding material allowables (i.e., yield strengths).

(U) Regarding low-frequency responses, only blast loading was analyzed since it was found to be more critical than cold and hot X-ray loadings. The approach to assess blast response is illustrated by the flow diagram of Figure 6.4.3-5. The centerpiece of the analysis is the low-order full-body model dynamic analysis. The required warhead spring and mass constants were calculated using the warhead stiffness and mass distribution information supplied from LLNL.

(U) The results showed that the highest stresses occurred near the manufacturing joint area. However, these stresses were below material limits. The LL5-4c stresses were higher than those of a similar design, LL5-4a (See Section 6.4.5) which had a lighter NEP and a more aft located CG. The stresses at the aft support region were well below yielding due to the strong "wishbone" support design. The DOE/DoD component relative deflection responses pose no concern with the current designs.

6.4.7.4 (U) LL5-4c Candidate Feasibility Statement

(U) Based on the current design information and the assessments performed, the LL5-4c concept is structurally feasible with potential modifications to the aft mount. The stresses in the aft warhead flange tapers should be examined more closely if this design is pursued.

6.4.8 (U) LL5-5 STRUCTURAL ASSESSMENT SUMMARY

6.4.8.1 (U) Design Description

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(U) The AF&F mounting ring remains basically similar to the W88/MK5. The aft warhead support design is a two-piece IH type attachment, i.e. in-line, direct attachment. (See Figure 6.4.8-4). The NEP length and axial position has resulted in the need for a double curvature seal cover (Figure 6.4.8-1).

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6.4.13.2 (U) LA5-4 Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The approach used to assess the LA5-4 concept was to compare the design attributes of the forward wedge support area and the aft warhead support to designs that have already be assessed. (See Figure 6.4.13-1). The LA5-4 concept has an aft warhead support design that is similar to the LA5-6 design. The LA5-6 design was extensively analyzed by finite element models. Since the LA5-4 design concept is similar to the above mentioned design, a comparison of the loads and mass properties was made to determine the feasibility of the LA5-4 design. The seal cover and the wedge area are similar to LA5-6 and were assessed based on that design. (See Figure 6.4.13-1). The warhead attachment, the wedge, and the seal cover designs were assessed for the three critical MK5 V–γ trajectories (upper middle-UM, upper left-UL, and upper right-UR) by comparison.

(U) Assessment Results

(U) It is recommended that the warhead interface ring base at the warhead/ring interface be increased in the axial direction to give the ring a better moment capability. If this change is incorporated into the design, then the assessment of the LA5-4 aft warhead support and the forward wedge support area will have margins equal to or greater than the W88/MK5 design. This assessment was based on a loads and mass properties comparison between LA5-4 and LA5-6. The seal cover has positive margins based on the assessment of LL5-1 configuration that had similar geometry.

6.4.13.3 (U) LA5-4 Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

[redacted] The LA5-4 candidate employs the same forward sleeve configuration as the LA5-6 candidate.

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(U) Structural Vulnerability Assessment

(U) For the LA5-4 candidate only the substrate stress response in the vicinity of the aft support under side-on impulse loading was examined for high frequency responses because evaluation of a similar design (LL5-1) has indicated that this environment most stressed this design configuration.

(U) The LA5-4 aft mount high-frequency responses were expected to be within material limits due to similarity in the design to LL5-3a, which was found to be acceptable (See section 6.4.3).

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(U) Low-frequency response analysis concentrated on the blast loading environment because, again it was found to be more critical than the cold or hot X-ray loadings.

(U) The approach to assess the blast response is illustrated by the flow diagram of Figure 6.4.3-5. This analysis was carried out using a warhead model established from LANL supplied warhead mass distribution and stiffness information. The calculated forward and the aft support stiffness of LL5-3a were used for the LA5-4 analysis because of design similarity.

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FIGURE 6.4.14-2

(U) NEP COMPARISON

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FIGURE 6.4.14-3

(U) FORWARD WARHEAD SUPPORT

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FIGURE 6.4.14-4

(U) AFT WARHEAD SUPPORT

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(U) Structural Vulnerability Assessment

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Selection of an adequately stiff wedge material was viewed as an issue for this component due to the potential shift of loading from the forward to the aft warhead mount. Also, the NEP has a longer forward reach than the W88 which results in a small gap between the NEP and the AF&F support. An adequate gap between the NEP front end and the AF&F would be required to prevent physical impact. Additional design and component stiffness information would be required to provide a more complete assessment.

6.4.14.4 (U) LA5-5 Candidate Feasibility Statement

(U) Analysis of the LA5-5 candidate design was accomplished utilizing a conceptual drawing and general mass property information. This is considerably less information than has been received for many of the other candidates and as such, has much larger uncertainties associated with the assessment conclusions. With these caveats in mind the LA5-5 design was assessed to be structurally feasible with modifications to the forward warhead support and possibly to the AF&F support ring.

(U) It should be noted though, that this candidate was outside the weight and center of gravity limits imposed by LMSC (see Figure 6.2-1). The added weight (i.e., higher ballistic coefficient) caused the reentry body to have a higher terminal velocity and greater total heating during normal reentry which violates MK5 heatshield criteria.

6.4.15 (U) LA5-6 STRUCTURAL ASSESSMENT SUMMARY

6.4.15.1 (U) LA5-6 Design Description

The AF&F mounting ring remains basically similar to the W88/MK5.

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DTRA

The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE. The connector on the aft closure will require RF and thermal protection. Other than the addition of the connector on the aft closure its design remains very similar to the W88/MK5. Candidate mass properties (RB weight and CG location) are shown in Figure 6.2-2.

(U) This design provides compatibility with DoD hardware including the modification of the AF&F. An alternate AF&F configuration using the existing AF&F would require that additional components be packaged in the RB to accommodate one of the new safety strong links. This configuration was not

b(3)
DOE
DTRA

FIGURE 6.4.15-1
(U) LA5-6 FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 6.4.15-2
(U) NEP COMPARISON

FIGURE 6.4.15-3

(U) FORWARD WARHEAD SUPPORT

6.4.15.3 (U) LA5-6 Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

(U) For the proposed LA5-6 concept (see Figure 6.4.15-1) a stiffening sleeve was used to provide buckling strength for the aeroshell and to provide support to the warhead during structural vulnerability encounters.

DOE b(3)

DOE b(3)

b(3) DOE DTRA

DOE b(3)

(U) Structural Vulnerability Assessment

(U) The high-frequency responses for the LA5-6 design were investigated for a side-on impulse because evaluation of a similar design (LL5-1) had indicated that the side-on impulse was of most concern. Only the substrate stress response in the vicinity of the aft support was examined, again due to similarity of design. A local DYNA3D finite element model was developed to predict the local stress response in the aft support vicinity (see Figure 6.4.15-5). The results showed that the peak stresses developed at critical points in the substrate and in the connecting bolts and brackets were below the corresponding material allowables (i.e., yield strengths).

(U) With regard to low-frequency responses the candidate was evaluated for its and

b(3)
DOE
DTRA

FIGURE 6.4.15-5

(U) HIGH FREQUENCY (IMPULSE) RESPONSE RESULTS FOR LA5-6

performance under blast loading conditions because it was more critical than cold hot X-ray low-frequency loadings.

(U) The approach to assess the blast response was the same as that used for LA5-4 (see Figure 6.4.3-5). The centerpiece of the analysis was the low-order full-body model dynamic analysis. The required warhead forward and aft support stiffness data was determined from separate DIAL finite element analyses. The required warhead spring and mass constants were calculated using the stiffness and mass distribution information supplied by LANL.

(U) The results showed that the most critical responses occurred in the vicinity of the aft warhead support (see Figure 6.4.15-6). The highest stress occurred at the substrate outside surface located at the forward edge of the aft support on the hit side. The substrate stress exceeded the static material (aluminum) yield strength. Modification of the aft warhead mount to a wishbone-type design or increasing the mount thickness could alleviate the substrate yielding if it were found to be an issue in a later development phase.

(U) The DOE/DoD component relative deflection responses at known physical impact locations indicated that they were smaller than those in the W88/MK5 and therefore were not a concern

6.4.15.4 (U) LA5-6 Candidate Feasibility Statement

[redacted]

b(3)
DoE
DTRA

[redacted]

6.4.16 (U) LA5-7 STRUCTURAL ASSESSMENT SUMMARY

6.4.16.1 (U) LA5-7 Design Description

The AF&F mounting ring remains basically similar to the W88/MK5.

b(3) DOE DTRA

The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE. The connector on the aft closure will require RF and thermal protection. Other than the addition of the connector on the aft closure its design remains very similar to the W88/MK5. Candidate mass properties (RB weight and CG location) are shown in Figure 6.2-2.

(U) This design provides compatibility with the DoD including the modification of the AF&F. An alternate configuration using the existing AF&F would require that additional components be packaged in the RB to accommodate one of the new safety strong links. This configuration was not assessed due to insufficient data,

b(3)
DoE
DTRA

FIGURE 6.4.16-1
(U) LA5-7 FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 6.4.16-2

(U) NEP COMPARISON

DOE
DTRA 6(3)

(U) FORWARD WARHEAD SUPPORT

FIGURE 6.4.16-4

(U) AFT WARHEAD SUPPORT

although feasibility is likely. The proposed CAT-E PAL use control capability is feasible and the concept is compatible with all the missile physical and functional interfaces. The concept is close to the aerodynamic stability limit. A slight increase in weight in the forward area would improve this condition. (See Figure 6.2-1).

6.4.16.2 (U) LA5-7 Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The approach used to assess the LA5-7 concept was to compare the design attributes of the forward wedge support area and the aft warhead support to designs that have already been assessed (Figure 6.4.16-1). The LA5-7 concept has an aft warhead support design that is similar to the LA5-6 concept. The LA5-6 design was extensively analyzed by finite element models. Since the LA5-7 design concept is similar to the above mentioned design, a comparison of the loads and mass properties was made to determine the feasibility of the LA5-7 design. The wedge area is similar to the LA5-6 and was assessed based on that design. The seal cover design is a complex configuration that is basically flat as opposed to the normal concaved configuration. This seal cover is similar to one assessed on another program and was assessed based on that analysis (Figure 6.4.16-1). The warhead attachment, the wedge, and the seal cover designs were assessed for the three critical MK5 V–γ trajectories (upper middle-UM, upper left-UL, and upper right-UR) by comparison.

(U) Assessment Results

(U) The assessment of the LA5-7 aft warhead support designs and wedge area reflected margins equal to or greater than the W88/MK5 design. The seal cover has positive margins based on the assessment of a configuration that had similar geometry.

6.4.16.3 (U) LA5-7 Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

(U) For the proposed LA5-7 concept (see Figure 6.4.16-1) a stiffening sleeve was used to provide buckling strength for the aeroshell and to provide support to the warhead during structural vulnerability encounters. One issue associated with the sleeve was the response of the sleeve material to hot X-rays. Two sleeve configurations were examined just as for the LA5-6 candidate. See section 6.4.15.3 for a description of this work.

b(3)
DOE
DTRA

(U) Structural Vulnerability Assessment

(U) LA5-7 high-frequency responses were examined for the side-on impulse loading. Other candidate designs with similar configurations have shown that the impulse environment was most severe.

b(3)
DOE

(U) A DYNA3D finite element model was developed to predict the local stress response in this vicinity. The results showed that the peak stresses developed at critical points in the substrate and in the connecting bolts and bracket were below the corresponding material allowables (i.e., yield strengths).

(U) With regard to low-frequency responses the candidate was evaluated for its performance under blast loading conditions because it was more critical than cold and hot X-ray low-frequency loadings.

(U) The approach to assess the blast response was the same as that used for LA5-4 (see Figure 6.4.3-5). The centerpiece of the analysis was the low-order full-body

model dynamic analysis. The required warhead forward and aft support stiffness data was determined from separate DIAL finite element analyses. The required warhead spring and mass constants were calculated using the stiffness and mass distribution information supplied by LANL.

b(3) DOE

(U) The DOE/DoD component relative deflection responses at known physical impact locations indicated that the relative lateral deflection along the AF&F and the aeroshell substrate gap interface was most critical. The deflection value is higher than that of W88/MK5, however, it is still below the allowable.

6.4.16.4 (U) LA5-7 Candidate Feasibility Statement

b(3) DOE DTRA

6.4.17 (U) LA5-8 STRUCTURAL ASSESSMENT SUMMARY

6.4.17.1 (U) LA5-8 Design Description

b(3) DOE DTRA

b(3) DOE DTRA

The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE. The connector on the aft closure will require RF and thermal protection. Other than the addition of the connector on the aft closure its design remains very similar to the W88/MK5. Candidate mass properties (RB weight and CG location) are shown in Figure 6.2-2.

(U) This concept appears to provide compatibility with the DoD hardware including the modification of the AF&F. An alternate AF&F configuration using the existing AF&F would require packaging of additional components in the RB to accommodate one of the additional safety strong links. This alternate configuration was not assessed, but feasibility is likely. A CAT-E PAL use control capability is feasible if utilized on this design and the concept is compatible with all the missile physical and functional interfaces.

b(3)
DOE
DTRA

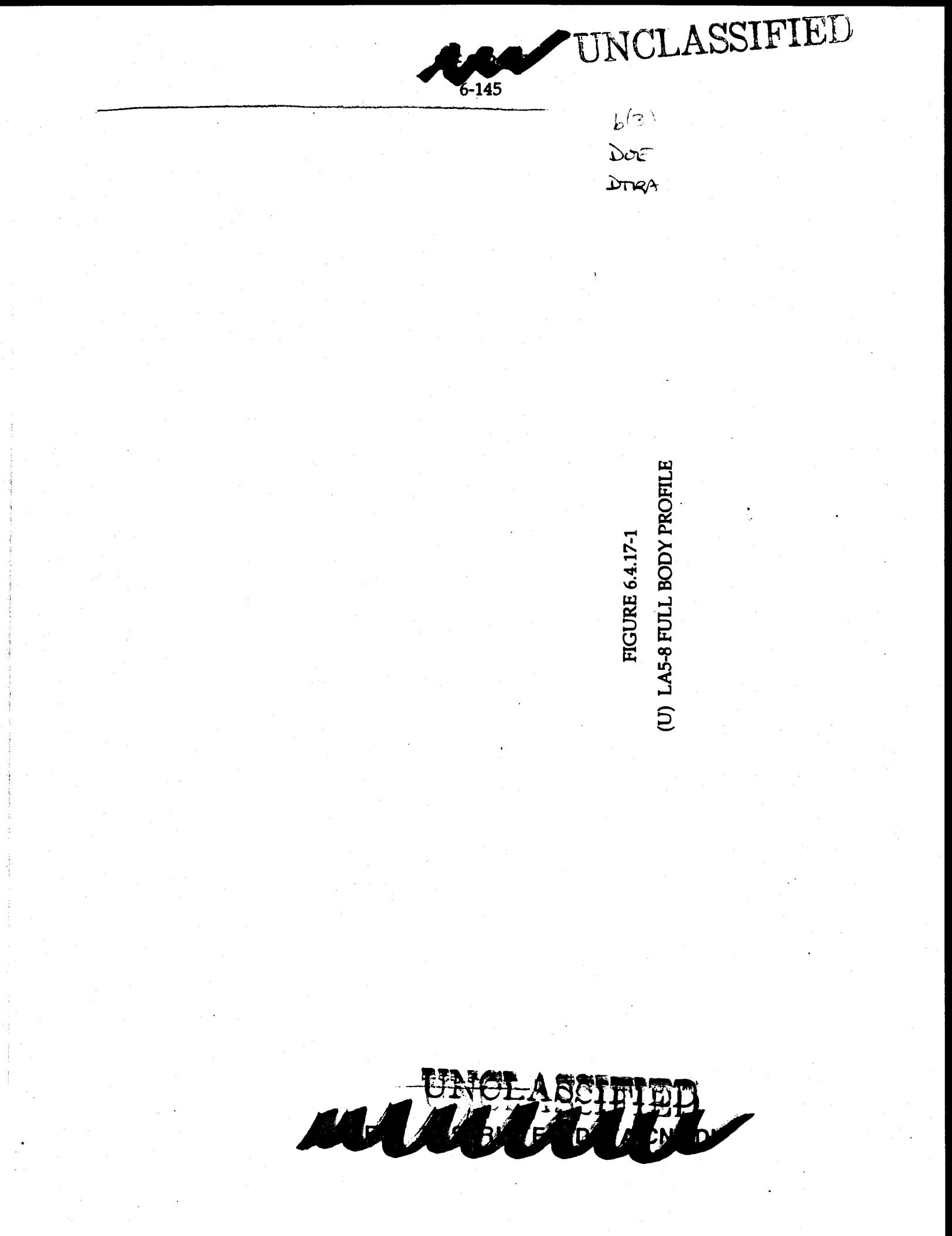


FIGURE 6.4.17-1
(U) LA5-8 FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 6.4.17-2

(U) NEP COMPARISON

b(3)
DOE
DTRA

FIGURE 6.4.17-3
(U) FORWARD WARHEAD SUPPORT

b(3)
DOE
DTRA

FIGURE 6.4.17-4

(U) AFT WARHEAD SUPPORT

6.4.17.2 (U) LA5-8 Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The LA5-8 design was assessed by engineering judgment based on limited details of a 8 1/2 x 11 layout shown in the "Excerpts from the Fourth SLBM Phase 2 Study Group", dated 4 March 1993. The aft warhead attachment is similar to the MK5 IH attachment. The LA5-8 was assessed based on the MK5 IH design concept. The forward support is the same as the MK5 concept and the seal cover is the MK5 design.

(U) Assessment Results

(U) It was assumed that because of the similarity of this design to the W88/MK5 attachment designs that positive margins of safety can be obtained for the LA5-8 concept. One area in the design needing additional assessment is the aft cover of the NEP. This can be refined if this candidate is pursued.

6.4.17.3 (U) LA5-8 Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

(U) Based on the known materials included in the design, there are no material vulnerability concerns.

(U) Structural Vulnerability Assessment

(U) The LA5-8 candidate is a straightforward design concept. With the design information available it was noted that the aft warhead mount was similar to the MK5 IH mount and appears to be feasible. The forward warhead support or wedge, being similar in shape to the W88/MK5, likewise appeared to be feasible.

b(3)
DOE

(U) Additional information concerning the sequence of events associated with the NEP including the possible orientation of the various LA5-8 NEP components, during hostile environment encounters would need further assessment.

6.4.17.4 (U) LA5-8 Candidate Feasibility Statement

(U) Analysis of the LA5-8 candidate design was accomplished utilizing a conceptual drawing and general mass property information. This is considerably less information than has been received for many of the other candidates and as such, has much larger uncertainties associated with the assessment conclusions. With these caveats in mind the LA5-8 design was assessed to be feasible with modifications to the NEP case and aft cover to the case. In addition, information describing the operation (sequence of events) of the NEP would be needed if this candidate is to be further developed.

6.4.18 (U) LA5-9 STRUCTURAL ASSESSMENT SUMMARY

6.4.18.1 (U) LA5-9 Design Description

b(3)
DOE
DTRA

The AF&F mount appears to be of the same design as the W88/MK5.

b(3)
DOE
DTRA

b(3)
DOE
DITRA

FIGURE 6.4.18-1
(U) LA5-9 FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 6.4.18-2

(U) NEP COMPARISON

b(3)
DOE
DTRA

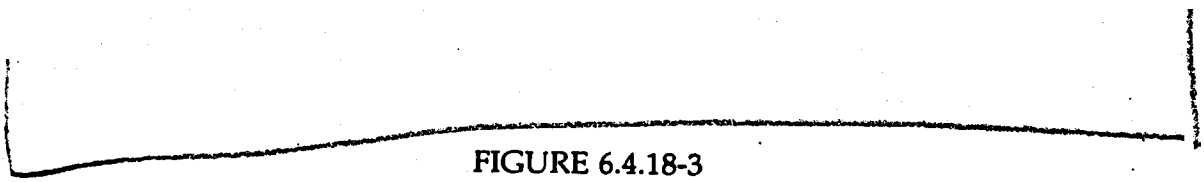


FIGURE 6.4.18-3

(U) FORWARD WARHEAD SUPPORT

b(3)
DOE
DTRA

FIGURE 6.4.18-4

(U) AFT WARHEAD SUPPORT

b(3) DOE DTRA

b(3) DOE

The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE. The connector on the aft closure, will require RF and thermal protection. Other than the addition of the connector on the aft closure its design remains very similar to the W88/MK5. Candidate mass properties (RB weight and CG location) are shown in Figure 6.2-2.

(U) This design provides compatibility with the DoD hardware including the modification of the AF&F. An alternate AF&F configuration using the existing AF&F would require that additional components be packaged in the RB to accommodate one of the new safety strong links. The configuration was not assessed, but feasibility appears likely. The proposed CAT-E PAL use control capability is feasible and the concept is compatible with all the missile physical and functional interfaces. The concept has good aerodynamic stability margins.

6.4.18.2 (U) LA5-9 Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The approach used to assess the LA5-9 concept was predicated on the design attributes of the forward warhead support wedge and the aft warhead support. (See Figure 6.4.18-1). The LA5-9 concept had an aft warhead support design that is similar to the MK5 IH design, and a forward warhead support wedge that is somewhat larger but is located slightly further aft than the W88/MK5 wedge. Since these two pieces of structure were similar to the MK5 tactical design, the MK5 capability curves were used to determine the feasibility of the design. A parametric study of the MK5 tactical nub concept versus the MK5 IH bolted concept established a set of knock-down factors that were used on this assessment to adjust for the difference between the MK5 tactical and the MK5 IH designs. The seal cover is a complex design that is basically flat as opposed to the normal concaved

configuration. This seal cover is similar to one analyzed on another program and was assessed based on that analysis. (See Figure 6.4.18-1). The warhead attachment, the wedge, and the seal cover designs were assessed for the three critical MK5 V–γ trajectories (upper middle-UM, upper left-UL, and upper right-UR).

(U) Assessment Results

(U) The assessment of the LA5-9 aft warhead support design reflected margins equal to or greater than the W88/MK5 design. The wedge concept has positive margins of safety. The seal cover has positive margins based on the assessment of a configuration that had similar geometry.

6.4.18.3 (U) LA5-9 Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

b(3)
DE (
DTRA

(U) Structural Vulnerability Assessment

(U) The LA5-9 candidate has a "wishbone" shape aft warhead support, and its foam wedge forward support is located further aft than that of the W88/MK5 (see Figure 6.4.18-3).

(U) Only the substrate stress response in the vicinity of the aft warhead support under side-on impulse loading was examined when high-frequency responses were evaluated. This approach was selected because evaluation of the W88/MK5, a similar design, had indicated that the impulse loading produced the most severe stress.

(U) A DYNA3D finite element model was developed to predict the local stress response in this vicinity (see Figure 6.4.18-5). The results showed that the peak

b(3)
DE
DTRA

FIGURE 6.4.18-5
(U) HIGH FREQUENCY IMPULSE RESPONSE RESULTS FOR LA5-9

stresses developed at critical points in the substrate and in the connecting bolts and bracket were below the corresponding material allowables (i.e., yield strengths).

(U) The approach to assess low frequency blast response is illustrated by the flow diagram of Figure 6.4.3-5. The centerpiece of the analysis was the low-order full-body model dynamic analysis. The required warhead spring and mass constants were calculated using the warhead stiffness and mass distribution information supplied from LANL.

(U) The results showed that the highest stresses occurred near the manufacturing joint area, however, their estimated magnitudes were still below allowable limits. The DOE/DoD component relative deflection responses at potential physical impact locations indicated that the relative lateral deflections between the warhead and the aeroshell substrate were the most critical. Additional analysis of the forward support deflection is recommended.

6.4.18.4 (U) LA5-9 Candidate Feasibility Statement

(U) Analysis of the LA5-9 candidate was accomplished with the following conclusion: the LA5-9 candidate design is feasible with possible modifications to the forward warhead support.

deployment. This Phase 2 study was undertaken with the knowledge that tradeoffs with performance would likely be necessary to achieve improvements in safety and security in this highly optimized system. Those tradeoffs are discussed elsewhere in the report.

b(3)
DOE
DTRA

(U) FIGURE 7.1-1

(b)
DOE
JTRA

(U) FIGURE 7.1-2

7.1.3 (U) AF&F AND ELECTRICAL SUPPORT SYSTEMS OPTIONS

(U) The AF&F and the other electrical support systems in the New Mexico Laboratories' proposed nuclear assembly packages for the MK4A address two specific Phase 2 Study issues, Use Control(UC) and Enhanced Nuclear Detonation Safety (ENDS). Specific implementation of UC and/or ENDS is addressed in the discussions and accompanying figures in the descriptions that follow for each candidate proposed.

[redacted] Three electrical configurations are proposed for the LA4 candidates on the D5 missile and two configurations on the C4 missile.

b(3)
DOE
DTRA

There are three electrical configurations proposed for the implementation of detonator enabling/safing for the LA4 candidates on the D5 missile and two configurations on the C4 missile.

(U) The first configuration proposed (C4 and D5) requires a complete rebuild of the MK4 AF&F. Most of the AF&F subsystems and components would be recovered during disassembly, tested, recertified, and reassembled into the new AF&F. The SALAD type device electrical system would be included in the expanded exclusion region inside the AF&F. A new, higher voltage thermal battery would replace the existing 500-volt battery to increase the fire set charge potential so that the existing fire set could fire slapper detonators. No additional electrical components are required inside the reentry body.

(U) The second configuration proposed (again C4 and D5) requires only minimal MK4 AF&F modification to replace the existing thermal battery with a higher voltage output unit. Additional components and systems are required within the

reentry body and the release assembly to provide appropriate power and control of the detonator enabling/safing system. An Environment Sensing Signal generating Device (ESSD) is required to generate and process unique signals that are used inside the reentry body to enable and trigger the SALAD type device.

(U) A third configuration is proposed for use on the D5 missile system only. Unique signals available at the MK5 platform interface (MK5 Data and Data Return) replace those signals generated by the ESSD assembly described in the configuration above. DoD hardware modifications are required to provide new cabling and connectors to and through the MK4 platform and the aft and seal covers.

7.1.4 (U) MK4 NUCLEAR SYSTEM DESCRIPTIONS

b(3) DOE DTRA

7.1.4.1.1 (U) *Origin/Basis*

b(3) DOE DTRA

7.1.4.1.2 (U) *General Description/Performance*

b(3) DOE DTRA

UNCLASSIFIED

b(3)
DOE

(U) FIGURE 7.1-4

UNCLASSIFIED

UNCLASSIFIED

b(3)
DOE
DTRA

UNCLASSIFIED

b(3) (
DOE
DTRA

(U) This system is calculated to be one-point safe. Multipoint safety evaluation, such as the exploding rocket bottle scenario, has not yet been performed.

7.1.4.2.1 (U) *Secondary Design*

b(3)
DOE
DTRA

(U) Nuclear System Engineering

b(3)
DOE
DTRA

(U) This warhead uses the same seal cover and AF&F which is currently in the MK4. The forward mount uses the same mounting holes but is slightly modified from the MK4 mount The aft mount is a foam mount similar to the MK4 aft mount. The gas transfer system is an Acorn.

7.1.4.2.2 (U) *Electrical Support System*

The electrical support systems for LA4-2 are identical, with one exception, to those proposed for LA4-1.

b(3)
DOE
DTRA

7.2.2 (U) NUCLEAR EXPLOSIVE PACKAGES

7.2.2.1 (U) LL4-1a (Baseline)

7.2.2.1.1 (U) *Warhead Description*

[redacted]

b(3)
DOE
DTRA

b(3)
DoE
DTRA

FIGURE 7.2-1
(U) SUMMARY OF LL4 CANDIDATES

The LL4-1a candidate provides fully modern safety features. It has been calculated to be conservatively one-point safe. Its ENDS protection includes DSSL.

b(3)
DoE
DTRA

As noted above, the LL4-1a candidate provides IHE and a fire resistant pit (FRP). Its estimated INRAD values are shown in Table 7.2-1. b(3) DOE DTRA

[redacted] The LL4-1a candidate offers a CAT-E PAL option.

b(3) DOE DTRA

(U) The LL4-1a NEP emphasizes traditional warhead production technology, except for pit reuse. A facility to modify reused pits for use in new warheads is being developed in a cooperative effort between LLNL and the Pantex Plant. This development was motivated by the W89 program, but because of its generic utility, it has continued unabated even after the W89 program was canceled in July 1992. This effort is far less than would be required to establish a new plutonium fabrication facility. Pit reuse avoids the need for such a new facility. There are no identified issues that limit the longevity of a LL4-1a warhead. The NEP inside the MK4A has good vulnerability and hardening (V&H) characteristics.

TABLE 7.2-1

(U) SUMMARY VALUES FOR LLNL/SANDIA MK4A CANDIDATES

b(3) DOE DTRA

7.2.2.1.2 (U) *Nuclear Test Status*

b(3) DOE DTRA

7.2.2.1.3 (U) *Summary Of LL4-1a*

b(3) DOE DTRA

The LL4-1a is feasible, and because of its combination of good characteristics, it has been chosen as the baseline LLNL/Sandia MK4A warhead candidate.

7.2.2.2 (U) LL4-2a

7.2.2.2.1 (U) *Warhead Description*

b(3) DOE DTRA

There are no identified issues that would limit the longevity of a LL4-2a warhead. The LL4-2a NEP inside the MK4A RB has good V&H capabilities.

7.2.2.2.2 (U) *Nuclear Test Status*

b(3)
DOE
DTRA

7.2.2.2.3 (U) *Summary Of LL4-2a*

The LL4-2a candidate is feasible

b(3)
DOE
DTRA

7.2.2.3 (U) LL4-3a

7.2.2.3.1 (U) *Warhead Description*

b(3)
DOE
DTRA

INRAD values are shown in Table 7.2-1. Except for fabrication of a new pit, its producibility is good. However, because of its requirement for new pit fabrication, there is no near term prospect of its production in the DOE complex. There are no identified issues that would limit the longevity of a LL4-3a warhead. The LL4-3a NEP in the MK4A RB has good V&H capabilities.

7.2.2.3.2 (U) *Nuclear Test Status*

[redacted]

b(3) DOE DTRA

7.2.2.3.3 (U) *Summary Of LL4-3a*

(U) The LL4-3a candidate is the most robust and best performer of the LLNL/Sandia MK4A warhead designs. It also has the lowest INRAD. If new pits could be fabricated, it would be the LLNL/Sandia baseline design. However, because there is no near term prospect for its production, LL4-3a is an excursion that illustrates the benefits that come with a custom designed pit.

7.2.2.4 (U) LL4-1b, LL4-2b, and LL4-3b (New AF&F)

(U) Each of the above MK4A candidates has a "b" version with essentially the same NEP. These candidates are labeled LL4-1b, LL4-2b, and LL4-3b. In each "b" candidate the existing AF&F is replaced. This change offers the opportunity to place a second stronglink at the detonator, in addition to DSSL. This is done by replacing the booster pellets in the primary IHE with voids that will prevent initiation of the IHE, even if the detonators function properly.

b(3) DOE DTRA

The NEPs in the "b" candidates are the same as in the corresponding "a" candidates, except for the change in the booster pellets. Their development nuclear test requirements are the same as for the corresponding "a" candidates.

b(3) DOE DTRA

7.2.2.5 (U) MK4A NEP Summary

b(3) DOE DTRA

7.2.3 (U) WARHEAD COMPONENTS

7.2.3.1 (U) Electrical Systems

(U) There are three electrical systems available for the LL4:

1. A system that uses the W76 AF&F with its stronglinks and does not add any detonator safing;

2. A system that uses the W76 AF&F and adds detonator safing (DSSL) and a separate unique signal generator or auxiliary programmer;

3. A system that includes both DSSL and PEX Booster detonator safing. This system requires a new AF&F.

(U) Variants are possible within each of these themes as to how the unique signals are generated, the type of use control, etc.

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LL4-1a,2a,3a with DSSL and ESSG (C4 and D5)

b(3)
DOE

FIGURE 7.2-2
(U) ELECTRICAL SYSTEM BLOCK DIAGRAM FOR C4/D5 USING MC2912 AF&F

UNCLASSIFIED

UNCLASSIFIED

11.4-1a.2a.3a with DSSL (Modified D5)

b(3)
DOE

FIGURE 7.2-3
(U) ELECTRICAL SYSTEM BLOCK DIAGRAM FOR MOD-D5 USING MC2912 AF&F

(U) All MK4 signals will be used as currently defined for the W76/MK4 at the field joint connector. The MK5 Data line could provide the unique signal information (including Intent) in the modified-D5 application. The proposed changes required to the MK4 adapter to obtain the in-flight unique signals for the modified-D5 application are shown in Figure 7.2-4. If the cable in the D5 adapter cannot be changed and the D5 data is not available, an ESSG would be used on D5 that would be similar to the ESSG used on C4 but optimized for D5 environments.

(U) The IFD for the W76/MK4 does not have sufficient number of pins for passing the unique signals required by DSSL. Replacing the 11-pin MK4 IFD insert with the 14-pin MK5 insert would correct this problem. This change will also require new cables to and from the IFD (i.e., on the RA and inside the RB). The additional conductors will be used to drive the DSSL directly from either an Environmental Sensing Signal Generator (ESSG) for the C4 and D5 application, or an auxiliary (in addition to the AF&F programmer) programmer for the modified-D5 application. The ESSG and auxiliary programmer will be mounted on the RA. The auxiliary programmer will receive the unique signal information from the MK5 Data line, which is available at the field joint connector with the changes to the MK4 adapter shown in Figure 7.2-4. The auxiliary programmer will use either the D5 unique signal information or a self-contained ESSG to generate the DSSL drive signal.

(U) Environmental-Sensing Signal Generator (ESSG)

(U) Portions of the environmental unique signal will be generated during powered flight and the remainder will be generated after RB separation from the RA. (The generation of the unique signal is addressed in more detail in Section 7.2.5.) While the post-separation portion of the unique signal must be generated by an ESSG on-board the RB, the powered-flight portion of the signal can be generated by an ESSG external to the RB. Locating this ESSG external to the RB allows the RB to be disconnected from the ESSG during shipping and storage, thus reducing the chance of inadvertent generation of the unique signal. The ESSGs will be based on technology similar to the W88 programmer (MC3811). The external ESSG will be located on the Release Assembly. Because it is not in the sealed volume, it will be hermetically sealed. The ESSG within the RB will be integral with the Seal Cover.

(U) The external ESSG should be located where it could be installed at the time that the RBA is installed to the missile. Figures 7.2-5 and 7.2-6 show potential locations for the ESSGs on the C4 and D5 RAs. The shipping container would be configured such that the RBA cannot be installed with the auxiliary ESSG attached. Safety could be improved further by the use of a Read-only Memory (ROM) key. This key would contain information necessary to generate the proper unique signal. The key would be configured as a simple connector. It would be installed on an ESSG connector during RBA mating to the missile and would be removed during demating.

(U) On the modified-D5, the unique signals would be supplied by the missile and the external ESSG would not be needed. However, the ESSG/programmer internal to the RB would always be present to allow the RB to be used on C4.

(U) The battery within the AF&F is not capable of driving DSSL. New batteries are required to operate the system with DSSL. One battery would be located on the RA. This battery would operate the ESSG (on C4 and unmodified D5 missiles) and advance the DSSL as the unique signal information was delivered to the internal programmer during powered flight. Another battery would be located in the RB, aft of the Seal Cover. This battery would power the programmer and ESSG within the RB and drive DSSL for the post-separation unique signal events. The on-board battery would be actuated by a signal from the external battery.

(U) The battery on the RA would be actuated by a G-Time sensor that would have a mechanical unlock mechanism. This mechanism is used to prevent premature actuation of the battery during transportation. The mechanism would be locked during transportation and unlocked immediately prior to installing the RBA onto the missile. The battery will use cobalt disulfide technology.

(U) The low voltage cable in the MK4 will have to be redesigned. The replacement cable will be a flat-flex cable. Two additional cables for the CAT-E PAL system are required. The cable from the seal cover to the aft cover will have to be replaced to accommodate the new auxiliary ESSG or programmer and battery.

(U) These candidates could also be produced without either DSSL or CAT-E PAL.

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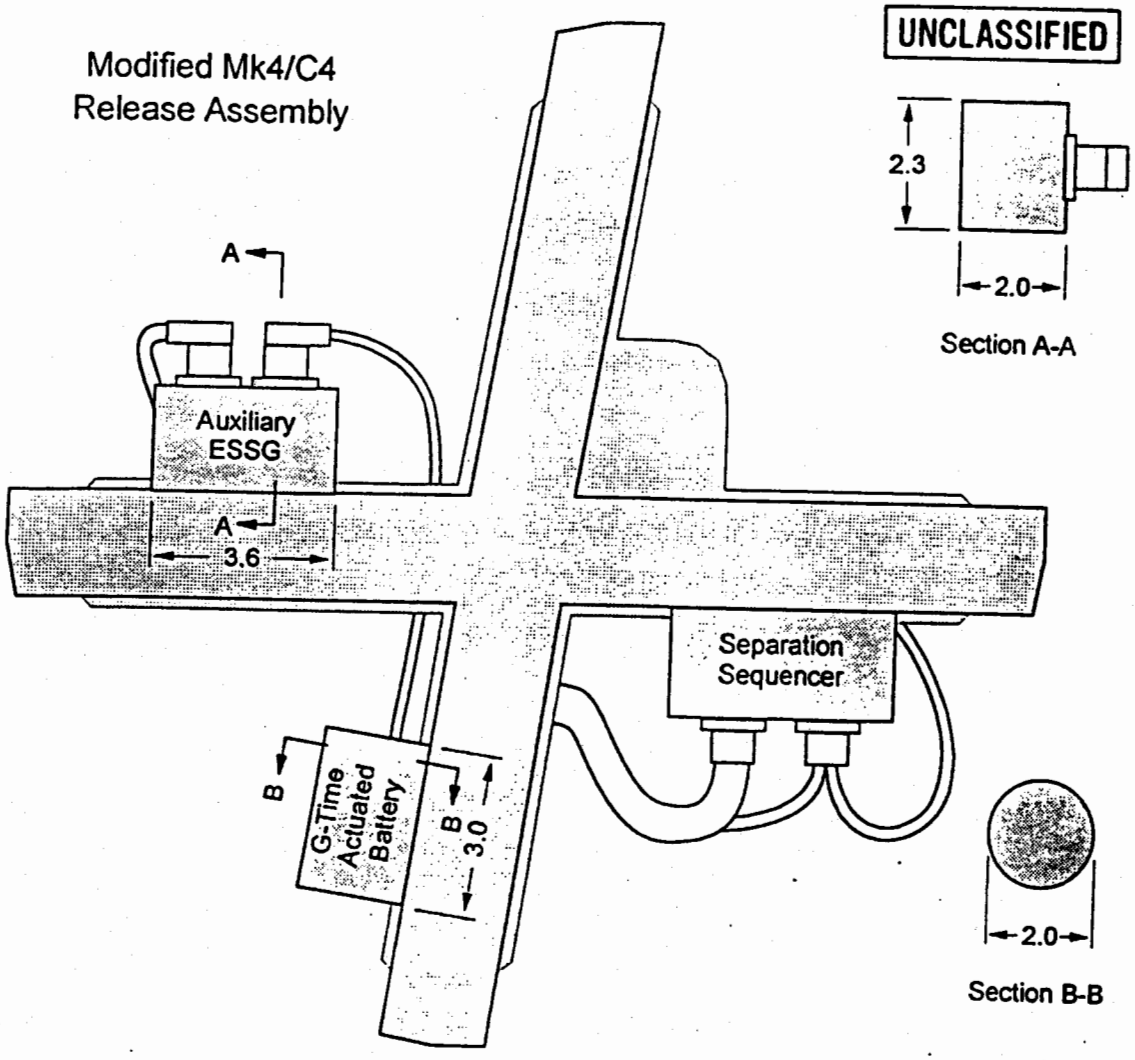


FIGURE 7.2-5
(U) ESSG MOUNTING ON C4 RA

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(U) The elimination of DSSL would delete the ESSG, the external programmer and the battery from the RAs and allow the use of the standard MK4 and MK5 RAs and adapter plate and cabling. The MK4A would not need the MK5 IFD insert and could use the MK4 IFD insert. The D5 MK5 Data Line would not be used.

(U) The elimination of CAT-E PAL would negate the need for the additional connector on the aft closure and seal cover and the associated cabling.

(U) The design could also be modified to incorporate Category D PAL. CAT-D PAL will require a programmer in the RB.

7.2.3.1.2 (U) *Based On New AF&F (LL4-1b, -2b, and -3b)*

(U) Block diagrams of the proposed electrical system for the MK4A using a new AF&F are shown in Figure 7.2-7 for the C4 and D5 applications and Figure 7.2-8 for the modified-D5 application. The majority of the new AF&F would be located in the same location as the old AF&F and would include a PEX system and the on-board ESSG. The only portion of the AF&F not located forward of the NEP is the fireset, which is integral with the Seal Cover. The packaging of the PEX Booster system into the new AF&F is shown in Figures 7.2-9 and 7.2-10. The PEX Booster concept and operation are described in detail in Section 5.2.5.3.

(U) The new AF&F will use technology similar to that used in the MK5 MC3719 AF&F. The ESSG/programmer in the new AF&F will use technology similar to that used in the W88 programmer (MC3811).

(U) The fireset will use capacitor discharge unit (CDU) technology similar to that used in the W87/MK21 (Peacekeeper). Because this design relies on DSSL and the PEX booster, no stronglinks are required in the fireset.

(U) The new MK4 AF&F will function much like the MK5 AF&F, and therefore require power during the entire flight of the RB. Two batteries are required; a low voltage-long life battery, and a short term negative-voltage battery. The new low voltage battery will be located in the front of the RB behind the impact fuze. The negative-voltage battery will be located in the rear of the AF&F, where the fireset was in the old AF&F.

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FIGURE 7.2-8
(U) ELECTRICAL SYSTEM BLOCK DIAGRAM FOR MOD-D5 USING NEW AF&F

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7.2.4 (U) PACKAGING AND MOUNTING

7.2.4.1 (U) Forward Mount

(U) The three LL4 NEPs have very similar configurations and dimensions which allows their mounts to be similar to one another.

The forward mount provides both axial and lateral support. Its interface with the body section and the AF&F are identical to the W76 forward support.

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(U) Like the W76, the new forward mount attaches to the NEP with a tape joint. However, because of differences between the W76 and LL4 NEPs, the tape joint is in a significantly different location (Figure 7.2-11).

7.2.4.2 (U) Aft Warhead Support

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(U) SECTION OF FORWARD WARHEAD SUPPORT

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A section of the support is shown in Figure 7.2-12.

7.2.4.3 (U) Seal Cover

(U) The sealed volume of the RB is completed by the seal cover, which is bolted to the existing substructure flange located aft of the nuclear system. Designs that do not include DSSL would use seal covers similar to the W76 seal cover. Designs that include DSSL will require a programmer; this would be mounted to the inner surface of the seal cover.

7.2.4.4 (U) Shield

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7.2.5 (U) SAFETY

(U) From an IND safety perspective, all of the LL4 NEPs are the same. Therefore, they all use the same IND safety themes. The LL4 candidates provide all the modern warhead safety features of enhanced nuclear detonation safety (ENDS), IHE, and FRP. The designs can also include the additional protection provided by a detonator safing stronglink (DSSL).

(U) The W76/MK4 is the benchmark from which we would make improvements in the IND safety for MK4A candidates. The W76 encloses its fireset and trigger circuit in an exclusion barrier assembled from stainless steel and aluminum components. The entry of electrical signals through the barrier is normally controlled by routing the signals through two stronglinks in series. One stronglink is the MC2854 Accelerometer; the other stronglink is the MC2897 Decelerometer. These types of stronglinks are referred to as Environmental Sensing Devices (ESDs). The detonator leads external to the NEP

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FIGURE 7.2-12
(U) SECTION OF AFT WARHEAD SUPPORT

are enclosed by the AF&F, the reentry body section (that is constructed of aluminum covered with carbon phenolic heatshield), and the aft closure and seal cover (both of which are aluminum).

(U) The LL4 designs can improve two aspects of the W76 nuclear safety theme:

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(U) To provide positive protection even if the NEP becomes exposed in an accident, the LL4 candidates include a Detonator Safing Stronglink (DSSL) downstream of the detonator cables, within the NEP itself. As long as the DSSL has not received the correct unique signal (i.e., been prearmed), firing of the detonator bridges cannot initiate the main charge explosive.

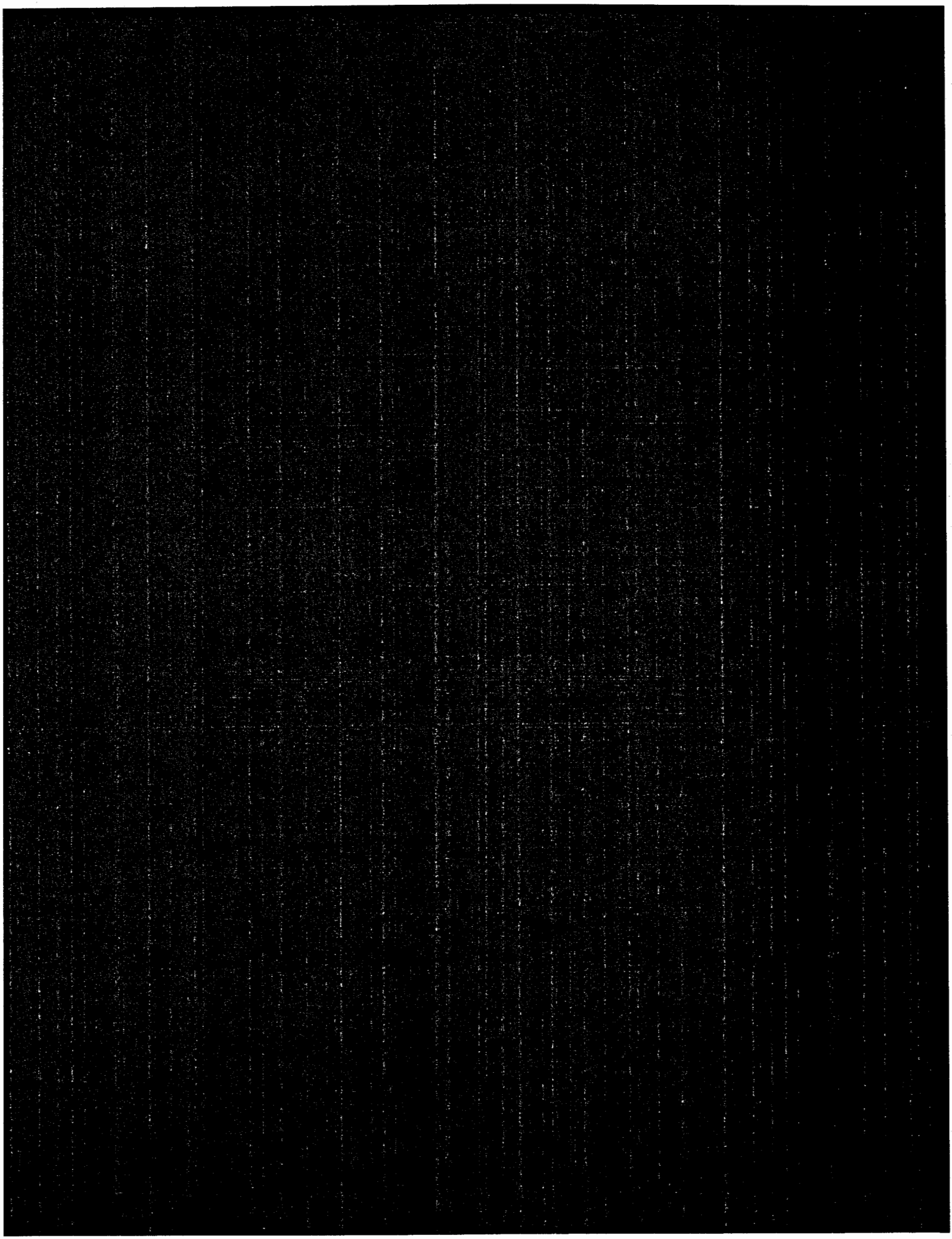
(U) The LL4 candidates that use a new AF&F add a second nuclear safety subsystem to the NEP by incorporating PEX Booster.

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These multiple event unique signals are carefully analyzed to verify that the probability of their inadvertent generation is much less than one in a million.

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is authorized for use. This use of a human intent signal to prearm DSSL provides the optimal safety for this design. However, the C4 missile system does not have any unique signal capability and therefore is currently incompatible with this implementation. Therefore for LL4 warheads on C4, an Environmental Sensing Signal Generator would construct a unique signal by sensing a series of combinations of go/no-go environmental inputs, including acceleration and electrical signals from the missile.

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7.2.6 (U) USE CONTROL

(U) Each of the LL4 designs is compatible with Category E PAL, Category D PAL (which requires a programmer within the RB), and command disable. These options are discussed in detail in the Use Control section of this report (Section 10.2).

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7.2.8 (U) STOCKPILE AND PRODUCTION CONSIDERATIONS

(U) The LL4-1a and LL4-2a designs use standard production technology developed in previous programs. There is nothing in these designs that presents unusual production problems to the DOE complex, except for the modification of reused pits, and the development of a pit reuse production facility is underway and progressing well.

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(U) The baseline producibility comments also apply to LL4-3a, except for the pit. The pit production technology was once standard (like the W87), but with the shutdown of the Rocky Flats Plant, the DOE complex no longer has the capability to produce such pits in quantity, and there is no near-term prospect for such a capability. Thus, while LL4-3a is the best performer and has significantly lower INRAD, it cannot be produced in the present DOE complex.

7.2.8.1 (U) Use Of And Modifications To DoD Hardware

(U) This section identifies the modifications necessary to implement our candidate designs.

7.2.8.1.1 (U) *MC2912 AF&F*

(U) LL4-1a, LL4-2a, and LL4-3a can use the existing MC2912 AF&F. Tests at Sandia have shown that the existing AF&F does not have enough energy to fire slapper detonators (such as are used in DSSL). This can be resolved by changing out one of the AF&F batteries with a new higher voltage battery, or re-designing the detonators to not use slappers. Rework of the AF&Fs to exchange the battery has been studied and is straightforward requiring machining of a weld and removal of the AF&F can.

(U) The fuze settings in the existing AF&F are not optimal and changing these settings would improve the effectiveness of any of these candidates.

(U) LL4-1b, LL4-2b, and LL4-3b do not use the existing AF&F. A new AF&F is required for these candidates.

7.2.8.1.2 (U) *Aft Body Section*

(U) All of the LL4 designs use the existing MK4 Reentry Body aft sections with no modifications.

7.2.8.1.3 (U) *Nose Tip*

(U) All of the LL4 designs use the existing carbon-carbon nose tips with no modifications.

7.2.8.1.4 (U) *Forward Body Section*

(U) All of the LL4 designs require modification to the aluminum substrate of the forward body section. Ballast must be mounted in the forward end of the reentry body to keep the overall RB center of gravity within specification.[3] The ballast could be attached to the forward body section, incorporated into a new fuze shield, or incorporated into a new or repackaged AF&F (for LL4-Xb candidates). LMSC analysis shows that substantial ballast (~10 lb) can be attached to the anvil of the forward section in the void area between the forward body section and the contact fuze on the AF&F. This is the minimal amount of modification that would be required for any of the LL4 designs.

7.2.8.1.5 (U) Aft Closure

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7.2.8.1.6 (U) *Release Assemblies*

(U) All the LL4 designs are compatible with the existing MK4 release assemblies. The candidates that use the existing AF&F and do not include DSSL can use the existing release assemblies without any modification to the RAs. However, any of the designs with DSSL will require components mounted to the RAs, e.g., ESSG, battery, and battery actuator. These components weigh about 3.5 pounds with an ESSG and about 1.5 pounds without an ESSG. These weights have not been included in the RB weight but should be considered in calculating missile and RB range capabilities. The components that must be mounted on the RAs are described in Section 7.2.3.1.

(U) Changes to the MK4 to D5 adapter cable to provide human Intent unique signals to the MK4A are discussed in Section 7.2.3.1.

7.2.8.1.7 (U) *RB Internal Cabling And In-Flight Disconnect*

(U) All of our MK4A designs using the W76 electrical system (MC2912 AF&F, no DSSL) can use the existing MK4 (11-pin) IFD and cable.

(U) Any of the candidates with DSSL will require the use of the MK5 (14-pin) IFD connector. The connector will need a right-angle backshell inside the aft closure to provide clearance for the components in the aft compartment. These designs also will need a new cable between the IFD and the seal cover to support the electrical systems that are shown in the schematics in Section 7.2.3.1.

7.2.8.1.8 (U) *Antenna System*

(U) The existing antenna system (antennas, cables, splitters, etc.) may be used without any changes for the LL4 designs that use the existing MC2912 AF&F.

(U) We have only briefly assessed the compatibility of the existing MK4 antenna system with a new AF&F. The new AF&F is based on the radar technology from the W88. The MK5 radar operates at different frequencies than the MK4 antennas are designed for. Whether it would be better for the new radar to operate at the MK4 frequency (compatible with the MK4 RB RF system) or operate at the MK5 frequencies (compatible with the MK5 radar, but not compatible with the MK4 antenna cavities) has not been

evaluated. We believe that the existing windows would not need to be changed. The performance of the modified system would not be as precise as the MK5, but could be better than the MK4.

(U) We have attempted to avoid packaging interference of the war reserve designs with the existing W76 JTA antenna system. However, we have given priority to the war reserve design -- changes to some of the JTA RF system cable routing and component mounting may be necessary for some of these candidates.

7.2.8.2 (U) Shipping And Storage Container

(U) The LL4 designs are compatible with the existing MK4 shipping and storage container.

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7.2.8.3 (U) Lifetime

(U) The comments relative to the lifetime of the LL5 candidates (Section 5.2.8.3) apply to the LL4 designs as well.

7.2.8.4 (U) Reliability

The reliability estimates for the LL4 candidates are shown in Table 7.2-2.

The estimates in the Table were calculated

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using the differences in the unreliabilities of candidate components relative to the corresponding W76 components.[4]

TABLE 7.2-2
(U) RELIABILITY OF LL4 CANDIDATES

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7.3 (U) THE 10 QUESTIONS OF DoD INSTRUCTION 5030.55

1. (U) What nuclear devices in production or under development appear to meet the requirement? What are the advantages and disadvantages of each? If no qualified devices are under development or in production, what are the characteristics of conceivable warheads that would meet this requirement?

   (U) No devices are in production or under development that meet the requirements. One existing device can be adapted to the MK4 RB with space and volume available for hazard protection.

   (U) Conceivable warheads that would meet the requirement(s) must provide increased safety over existing SLBM warheads, survive specialized environments of strategic reentry systems, and package in existing RBs.

2. (U) Considering only the development of this particular warhead/bomb, and without regard to other programs that might be conducted concurrently, what is the estimated length of time required for development after DoD request commencement of a Phase 3 development engineering project?

   (U) For pit reuse candidates, 5 year Phase 3, plus 2-3 years Phase 4 and Phase 5 first production before delivery to the DoD. If plutonium fabrication is required, delivery to the DoD would begin in over 10 years.

3. (U) In the context of the overall atomic energy program, what time scales might be expected for development after Phase 3 authorization during the course of a normal program? What technical development problems would be involved if the time scales were significantly decreased?

   (U) Same as above.

   (U) Decreased time scales would increase risk of fielding a warhead with a design flaw that would prevent meeting performance, surety or reliability goals.

4. (U) What development problems can be foreseen that appear difficult to solve? Do any problems require development effort on a scale that is greater or less than normal?

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[redacted] Candidates without this type of pit would not require this new facility.

5. (U) What special training operational, or logistical problems are foreseen concerning the warhead that should be considered for Phase 3 development engineering?

(U) The inclusion of use control features will impact the Navy's current logistics and operations.

6. (U) What, if any, additional experimental or theoretical investigation is required to establish feasibility?

(U) Beyond-one-point-safety analysis has not been performed for any candidate during Phase 2. Selection of a candidate would mean additional theoretical and possibly experimental investigation would be required.

7. (U) What is the technical evaluation and/or recommendation made by the DOE representatives concerning nuclear testing prior to weaponizing the device for stockpile?

(U) None of the MK4A candidates can be developed without further nuclear testing. See Section 12.3 for a summary.

8. (U) What possible technical or economic advantages or nuclear materials savings would accrue from reasonable warhead/weapon system tradeoffs and changes in the requirements stated in the authorization for the Phase 2 feasibility study such as use of "natural" versus specified yields, alternative warhead or limited life

8. COMPATABILITY OF MK4A CANDIDATES W/WS

8. (U) COMPATIBILITY OF MK4A WARHEAD CANDIDATES WITH THE WEAPON SYSTEM

8.1 (U) INTRODUCTION

(U) In June of 1992, a MK4A Phase 2 (Design Feasibility) effort was kicked off using the groundrules of Table 6.1-1. As part of this effort LMSC 1) defined allowable mass/center combinations within which the DOE laboratories could create various alternative warhead concepts and 2) assessed the feasibility and compatibility of each candidate concept with the MK4 on the C4 and D5 missile systems.

(U) Section 8.2 will summarize the analysis which produced the boundaries seen in Figure 8.1-1. Each of the boundaries represents limitations imposed by a component of the overall missile system. Section 8.2 will also describe the principal limits imposed by the MK4 on C4 or D5.

8.2 (U) MASS PROPERTIES LIMITATIONS

(U) This section summarizes the MK4A RBA and C4 or D5 missile component limitations imposed on the design RB candidates. Each of the limiting boundaries shown in Figure 8.2-1 will be identified and the limiting mechanism called out. The MK4A limits are as follows:

- Release assembly structural limit during first stage ignition
- Reentry body aerodynamic stability (during reentry)
- Maintain current MK4 Interface Control Drawing (ICD) minimum weight limit

For MK4A, all missile related limits were driven by the D5 missile.

8.2.1 (U) POWERED FLIGHT

(U) Several missile events were investigated during the early portion of Phase 2, that is, during the time the design space was defined. The impact of these events on RBA performance was assessed and limits drawn. The environments of concern include the following: 1) a stowage shock event; 2) underwater launch;

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FIGURE 8.2-1
(U) MK4A MASS PROPERTIES LIMITATIONS

3) first stage ignition and flight; 4) second stage ignition and flight; and 5) post boost flight and RB separation. Third stage ignition and flight were not seen as potential driving environments.

[redacted] Structural Mechanics evaluated several tactical MK4/D5 payload configurations with the objective of finding the limiting conditions to be imposed on the MK4A RBA on the D5 missile.

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8.2.2 (U) DEPLOYMENT/SEPARATION MECHANICS

(U) During the design space definition process no limiting condition was identified for separation mechanics which would further reduce the design space of Figure 8.2-1. Reentry body separation velocities and spin rates all varied as expected as weight and CG combinations were evaluated, but again no limiting condition was found.

8.2.3 (U) AERODYNAMICS

(U) Reentry Aerodynamics assessed the MK4 RB's ability to maintain basic stability as weight and CG were varied. Aerodynamically, there was no concern and

therefore no limitation for the CG in the most forward possible position (i.e., towards the nosetip). The objective was to define the most aft CG position for possible MK4A candidate designs, while still maintaining a positive static margin and hence a stable RB for the current flight environment ranges.

(U) The analysis concentrated on the UL null range and the LL zero angle of attack deployments as the trajectories that would set the CG requirements. For null range deployment minimum static margin occurs during high altitude reentry, while for zero angle of attack minimum static margin occurs at low mach numbers at impact (as the mach number decreases, the center of pressure moves forward toward the center of gravity).

(U) The aerodynamic analysis employed a Monte Carlo procedure to probabilistically determine the static margin. Nine weight/CG configurations were analyzed to define the limits shown in Figure 8.2-1. For the MK4A candidates the stability limit was initially selected to be 0.1% static margin, similar to the MK4. Given the inherent uncertainties which came with extrapolating aerodynamic performance at increased RB weights, an uncertainty area was defined which accounted for these uncertainties and which provided the Design Laboratories with a design space which encouraged them to keep the CG as far forward as possible.

8.2.4 (U) THERMODYNAMICS

(U) One of the concerns that was investigated for the MK4A RB Phase 2 candidates was the heatshield and substrate temperature performance. Increasing the total RB weight will increase the RB ballistic coefficient and accordingly the reentry velocities. The increased velocities will in turn increase the heat rates and potentially the total heating on the body (increased velocities will also reduce the down time, therefore a trade-off is made with heat rate and time in the atmosphere).

(U) Three separate regions in the aeroshell have temperature limitation criteria. First, the aluminum substrate temperature; second, the temperature of the bond material between the substrate and the heatshield; and third, the heatshield temperature 50 mils from the bondline. These criteria are not a limitation for the

MK4A candidates for principally two reasons: 1) the aeroshell cone angle is lower for the MK4A; and 2) more importantly, the MK4A RB has no weather cloud specification as a design requirement.

8.2.5 (U) ADDITIONAL LIMITATIONS ANALYSES

(U) In order to increase confidence in the calculated limitations and to assure ourselves that as many as possible of the design drivers had been investigated several other reentry body and missile body analyses were performed. None of the analyses described in this section limit the design space except the ICD minimum weight limit, although other limits exist just outside of the limits shown in Figure 8.2-1.

(U) MK4A Nosetip Erosion

(U) Performance of the MK4 CMT nosetip was evaluated relative to the variations in reentry body weight and center of gravity. Approximately 20% additional weight could be accommodated before the nosetip overhang would be used up and a limit imposed. It should be noted that the increased weight would result in an increased ballistic coefficient (higher reentry velocities) and that the stagnation pressure seen by the nosetip would be larger than current flight test experience.

(U) MK4A Nosetip Thermal Strains

(U) As part of the MK4A Phase 2 study, analysis was performed to qualify the MK4A CMT graphite nosetip over the entire velocity-gamma (V–γ) map for a 20% increase in reentry weight. In this study, the finite element structural analysis results together with failure criterion were used to evaluate the structural reliability. This failure criterion is based on statistical theory and considers multi-axiality of stress states, surface and internal flaw equivalence, grain orientation (across the grain and with grain), volume of tensile stress, and temperature effects.

(U) The analytical results indicate the structural reliability (probability of survival) exceeds 0.999 over the entire V–γ map for both the MK4A (20% increase in reentry body weight) and the MK4 tactical (nominal weight).

(U) MK4A Thruster Pad Stress

(U) With the increased weights being considered for candidate MK4A RBs, the resulting stress levels in the RB thruster pads were investigated. For the design space weight increases, thruster pad stresses remained below critical levels and therefore, was not a limiting issue.

(U) MK4A Heatshield Char Sloughing

(U) One area which has on-going analysis is char loss or char sloughing. The MK4 forward heatshield wrap direction (forward-facing) is known to experience sudden loss of the char-layer during flight on severe reentry trajectories (Upper-Middle). In the extreme, loss of the insulation performance of the char could lead to excessive temperature to the RB forward structure. There are studies underway to better understand char loss and the potential for multiple char losses. As criteria for char loss are established, they will be applied to the Phase 2 warhead designs to determine if a weight increase constraint should be adjusted.

(U) MK4A Moments of Inertia Variations

(U) In order to increase confidence in the calculated limitations and to assure ourselves that as many as possible of the design drivers had been investigated, several other reentry body and missile body analyses were performed. None of the analyses described in this section limit the design space except the ICD minimum weight limit, although other limits exist just outside of the limits shown in Figure 8.2-1.

(U) C4/D5 Nose Fairing and Third Stage Clearances

(U) An RB clearance analysis was made to see if the proposed Phase 2 weight/CG limits could cause any RB contact with the nose fairing (N/F) or third stage (T/S) motor during any stowage or boost phase events. For Phase 2, a weight/CG upper limit was defined for allowable designs (limited by the reentry body separation bolts, (see Section 8.2.1). The largest RB motions for the tactical D5 missile payloads occurred during the first stage motor ignition transient.

(SFRD) The critical MK4A D5 missile payloads (7 and 8 body configurations) were evaluated because these produced the largest RB radial loads. For these MK4A payloads and mass properties, there was no contact between the RB and N/F or T/S motor.

8.2.6 (U) MASS PROPERTIES SUMMARY

(U) The design space defined by the above mentioned limiting phenomena and shown in Figure 8.2-2 constituted the boundaries for the Design Laboratories. As noted on the figure, some areas in the weight/CG space were not assessed, but concepts would be evaluated case by case. All MK4A designs were in the appropriate design space.

8.3 (U) ELECTRICAL COMPATIBILITY

(U) This section describes the electrical compatibility assessments performed on the MK4A candidates. These assessments are divided into two sections. Section 8.3.1 describes the functional interface compatibility assessment which evaluates compatibility between the MK4A candidates and the C4 and D5 missiles. This section also includes a physical interface compatibility assessment of electrical components associated with the MK4A candidates. Section 8.3.2 addresses compatibility between the MK4A RBA and the existing W76/MK4 normal, abnormal, and hostile electrical environments, all of which were incorporated into the WXX/MK4A STS. Descriptions of MK4A use control features and their associated impacts on the C4 and D5 missile systems are provided in Section 10.

8.3.1 (U) FUNCTIONAL AND PHYSICAL INTERFACE COMPATIBILITY ASSESSMENTS

(U) The functional and physical interface compatibility assessments were top level evaluations which examined the functional and physical interface requirements of each of the MK4A candidates. Functional block diagrams of each of the candidates electrical systems and design similarity between the existing MK4 interfaces and the MK4A were used as a basis for the assessment because complete electronic system definition for any of the MK4A candidates has yet to be completed.

(U) The Phase 2 groundrules require that no changes are to be made in the physical or functional interfaces to the C4 and D5 missiles, except for software changes in fire control.

LANL/Sandia Candidates

(U) The electrical systems for LA4-1 and LA4-2 are identical, except for the addition of use control features on LA4-2. The electrical systems of candidates LA4-1 and LA4-2 are presented in the three following configurations:

A. New AF&F with Integrated Safing (C4 and D5)

(U) Electrical configuration A is based on a new AF&F design. The additional safety features are integrated into the new AF&F design resulting in no change to existing missile or MK4 RB cabling or connectors. This system is fully compatible with both the C4 and D5 missiles since it only requires existing MK4 electrical signals for operation. Therefore, this electrical system configuration is feasible based on functional and physical interface compatibility.

B. Modified AF&F: ESSG on RA (C4 and D5)

(U) Electrical configuration B is based on a modified AF&F design. It utilizes an Environmental Sensing Signal Generator (ESSG), battery, and G-switch mounted on the release assembly which provides the unique signals. This system is fully compatible with the C4 and D5 missiles since it only requires the existing MK4 electrical signals for operation. Therefore, this electrical system is feasible based on functional interface compatibility.

(U) This configuration requires a new sixteen pin IFD connector to accommodate the additional signals from the ESSG. A new connector is required since the existing connectors only have 14 pins maximum. This connector change does violate the Phase 2 groundrules.

(U) This sixteen pin system could be modified with the addition of multiplexing/ demultiplexing components in order to utilize a fourteen pin IFD connector, but there are potential weight and CG penalties associated with this modification which have not been fully assessed.

C. Modified AF&F: Utilizes MK5 Data Signals (D5 Only)

(U) Electrical configuration C like configuration B is based on a modified AF&F. It utilizes the MK5 data/data return lines in place of the release assembly mounted ESSG components to provide inflight data. To provide these signals to the MK4 requires modification to the "MK5 to MK4" adapter cable on the D5 missile. This violates program groundrules and would require further assessment.

LLNL/Sandia Candidates

(U) The electrical systems for the LLNL/Sandia candidates are provided in two configurations; one which utilizes an ESSG to provide the unique signals and one which utilizes the MK5 data signals from the D5 missile. The LL4-1a, LL4-2a, and LL4-3a utilize the existing MK4 AF&F which requires a separate DSSL driver, and the LL4-1b, LL4-2b, and LL4-3b candidates utilize a new MK4 AF&F which contains an integrated DSSL driver.

A. Existing AF&F: ESSG on RA (C4 and D5)

(U) Electrical configuration A is based on the existing MK4 AF&F. It utilizes an ESSG, G-Time actuated battery, and a mechanical lock mounted on the release assembly. These components are required to provide the unique signals. This system is fully compatible with the C4 and D5 missiles since it only requires the existing MK4 electrical signals from the missile for operation. It requires a fourteen pin connector to accommodate the three extra signals from the ESSG. No issues have been identified with this configuration; therefore, this electrical system is feasible based on functional and physical interface compatibility.

B. Existing AF&F: Utilizes MK5 Data Signals (D5 Only)

(U) Electrical configuration B like configuration A is based on the existing MK4 AF&F. It utilizes the MK5 data/data return lines in place of the release assembly mounted ESSG components to provide inflight data. A mechanical lock and G-Time actuated battery are also mounted on the release assembly. It requires a fourteen pin IFD connector to accommodate both the MK5 signals and the additional signal from the G-Time switch. To provide these signals requires modification to the "MK5 to MK4" adapter cable on the D5 missile.

8.3.2 (U) ENVIRONMENT COMPATIBILITY ASSESSMENT

(U) The environment compatibility/feasibility assessment was conducted to evaluate the compatibility between the STS normal, abnormal and hostile environments of an electrical nature and the MK4A candidates.

8.3.2.1 (U) Normal and Abnormal Environment Assessment

(U) The only normal environment of an electrical nature in the MK4A (and MK4) STS is the electromagnetic radiation environment (EMR). This environment also becomes an abnormal environment in the event the RB protective RF shield becomes damaged. The EMR environment includes an average power specification which is an adaptation of the Hazards of Electromagnetic Radiation to Ordnance (HERO) specification (Mil-Std-1385B), a peak power specification, an environment for an RB connected to test equipment or disassembled, and a deperming/degaussing environment. The two concerns associated with EMR are (1) the inadvertent initiation of ordnance devices, and (2) damage to electronic circuitry.

(U) Generally, EMR protection involves the shielding integrity of the RB which consists of the aluminum substrate and aft closure in addition to all the grounding, bonding, and shielding practices implemented in the original W76/MK4 design. Since these components and practices remain unchanged for the MK4A, and the MK4 margins for the environments are quite large, all of the MK4A candidates are feasible with respect to EMR. Design feasibility for any safing components located outside the aeroshell is not an issue as long as the same level of hardness is

incorporated into package design, especially if these packages contain sensitive electronic components or ordnance devices. Consequently, achieving feasibility with regard to EMR for all the MK4A candidates is not a concern.

(U) Protection against the lightning environment is mainly influenced by the same design attributes mentioned in regard to EMR. In addition to the aforementioned design attributes, the lightning arrestor connector (LAC) provides electrical protection by its voltage breakdown characteristics as demonstrated during MK4 development. Consequently, if this connector is used and similar grounding, bonding and shielding design attributes are implemented during the incorporation of additional electrical components as part of the MK4A program, feasibility with regard to the lightning environment should not be a concern for any MK4A candidate.

8.3.2.2 (U) Hostile Environment Assessment

(U) Electromagnetic effects such as electromagnetic pulse (EMP) are substantially mitigated by the shielding integrity of the RB. Since there are large margins associated with these environments and the grounding, bonding and shielding attributes associated with the MK4 aeroshell are unchanged, there are no issues associated with achieving feasibility for any candidate.

8.4 (U) INDIVIDUAL CANDIDATE STRUCTURAL ASSESSMENTS

(U) The approach taken to assess the structural feasibility of the individual Phase 2 candidate designs is illustrated in Figure 6.4-1. As shown, when the candidate designs were received an initial screening occurred which evaluated whether the candidate design fit within the weight and CG design space described in Section 8.2 (see Figure 8.2-1). Included in the screening was a check to see if an adequate set of analyses information was provided (i.e., candidate drawing, mass properties, mass distribution and stiffness). Then two sets of analysis were performed, one covering the candidate response to the normal reentry environments of the MK4A STS and one covering the candidate response to the hostile environments of the MK4A STS. The normal reentry analysis was performed first because of its more rapid

turn-around time. Feedback was then made to the Design Laboratories through the Design Integration Technical Working Group (DITWG). This feedback included both normal and hostile/vulnerability inputs.

(U) The approach taken by the normal and hostile/vulnerability reentry assessments is provided below. Both normal reentry and hostile reentry analyses produced statements of feasibility which are summarized in Table 8.4-1.

TABLE 8.4-1
(U) SUMMARY OF MK4A CANDIDATE
STRUCTURAL FEASIBILITY STATEMENTS

UNCLASSIFIED

Candidate	Feasibility	Comments
• LL4-1A	• Feasible as Proposed	
• LL4-1B	• Feasible with Potential Mod.	• AF&F Support Ring
• LL4-2A	• Feasible as Proposed	
• LL4-2B	• Feasible with Potential Mod.	• AF&F Support Ring
• LL4-3A	• Feasible as Proposed	
• LL4-3B	• Feasible with Potential Mod.	• AF&F Support Ring
• LA4-1	• Feasible with Reservations	• Insufficient Data to Adequately Assess
• LA4-2	• Feasible with Reservations	• Insufficient Data to Adequately Assess

(U) Normal Reentry

(U) The approach utilized during the normal reentry assessment consisted of the information flow illustrated in Figure 6.4-1 which culminated with the structural assessment. Existing MK4 and MK5 ground and flight test data, extensive reentry body design experience, design similarity and finite element modeling of the candidates were the tools used for analysis. Table 6.4-2 shows the analytic approach taken which was a function of the candidate design data received and the similarity of the design to past experience.

(U) Two reentry body to NEP design areas were of most importance to the normal reentry assessment. The configuration of the forward warhead support (or wedge) and the aft warhead support (or mount). The method of attachment and the type of material utilized each contributed in determining the analysis approach chosen. All of the candidate designs had common components in these two areas which aided in completing all of the analysis associated with twenty six or more candidates within the time allotted.

(U) Hostile Environments Approach

(U) To expedite the feasibility assessment, LMSC made maximum use of the available MK4 and MK5 RB analytical models developed from the prior MK4 and MK5 programs. One model used was the DYNA3D MK4 full-body model. This model was used as appropriate during the assessment considering: 1) the required degree of accuracy, and 2) the possibility of establishing concept feasibility by analogy/similarity and by inference from previous analysis and test experience.

(U) In order to accommodate the assessment of the large number of candidates that have been generated during the Phase 2 program, LMSC utilized similarity in the candidate's forward and aft mounting design features to assemble them into two groups for the MK4A candidates. This grouping was done to more efficiently analyze the many proposed candidates. As successive candidates from these groups were analyzed the performance/response of the aeroshell due to the common design feature was better understood and this understanding was then applied to subsequent candidate assessments. This increased understanding also applied to

identifying the hostile environment which most stressed the candidates and their common design feature. Figure 8.4-1 illustrates the two candidate groups associated with the MK4A.

(U) The baseline designs for all six LL4-X candidates include an Advanced Heather gas transfer system, although two other gas systems were available for use. During the LMSC vulnerability assessment the baseline system was utilized in the full-up analyses for each of the candidates. LMSC evaluated the LL4-1a design to see if variations in the gas transfer system would significantly alter component response. It was found that, for the weight variations seen between the three gas systems, component responses were similar and therefore, the feasibility statement made for each of the baseline systems apply for all of the possible gas systems.

(U) MK4A Single Forward Support Group

(U) For the MK4A Single Forward Support Group both the forward and aft support designs were significantly different from those of the W76/MK4. Therefore, a coupled full-body DYNA3D analysis was performed for two representative concepts, LL4-1a and LL4-1b. All three hostile environments, cold X-ray impulse, hot X-ray TSR and blast, were analyzed. The feasibility of the remaining concepts in this group was assessed based on similarity to these two candidates.

(U) MK4A W76/MK4-Like Support Group

(U) For the MK4A W76/MK4-Like Support Group both the forward and aft support designs are similar to the W76/MK4 design. The only concept in this group was LA4-1.

(U) The analysis approach chosen for each candidate was dependent on the design data provided. Table 6.4-2 illustrates the various types of data (levels of design definition) that were received from the DOE Laboratories and the associated aeroshell structural analysis approach(s) that could be taken. As can be seen from the table the level of design detail covers the spectrum of finite element model (FEM) to a sketch or drawing. Once an approach was identified the objective, as stated earlier, was to assess the design response to the hostile environments defined in the respective STS documents and to provide a statement of feasibility.

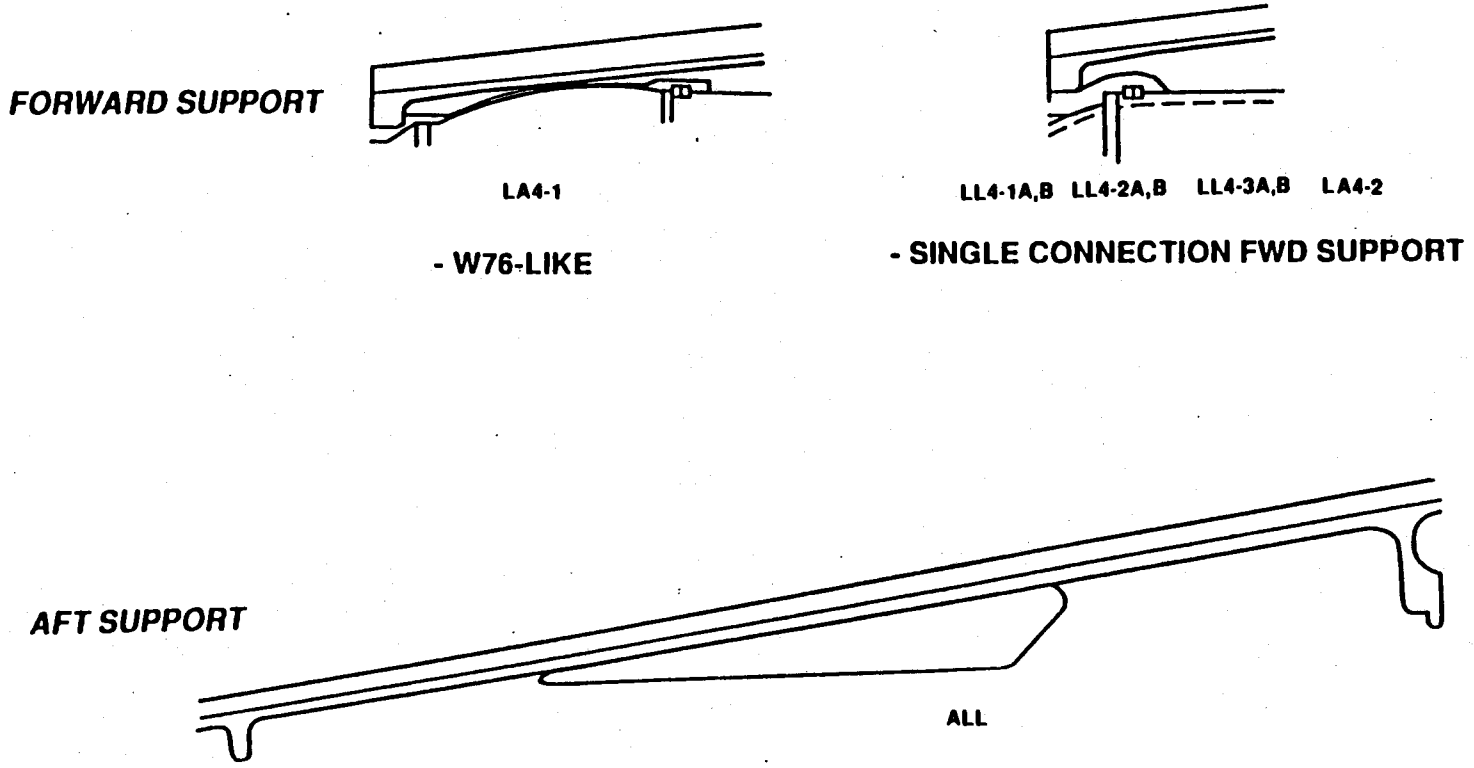


FIGURE 8.4-1
(U) MK4A GROUPS: SINGLE CONNECTION & W76-LIKE FORWARD MOUNTS

UNCLASSIFIED
UNCLASSIFIED

(U) The statements of feasibility were structured so as to cover the range of possible analytic conclusions, and are provided below:

1) the design is feasible as proposed or feasible with identified modifications,
2) the design is feasible with reservations,
3) the design is not feasible, or
4) insufficient data provided to adequately assess the candidate.

The second statement covers candidates where the identified design modification may not have a high level of confidence, or where the candidate requires a reduction in the hostile environment in order to be feasible, or where a reduction in candidate weight/center of gravity is required for candidate feasibility.

(U) Inherent in a Phase 2 study are uncertainties due to design maturity and uncertainties in modeling the performance of new design configurations. With this level of uncertainty, results which indicated yielding of component hardware were identified and design solutions recommended.

(U) Scope

b(3)
DOE
DTRA

(U) Structural vulnerability assessments of the reentry body aeroshell included the following: 1) evaluation of the relative deflection of DoD/DOE components (i.e., AF&F to aeroshell substrate, NEP to seal cover, and NEP to aeroshell substrate), 2) evaluation of forward warhead support stresses, 3) evaluation of aft warhead

support stresses, 4) evaluation of forward and aft substrate yielding and buckling at critical locations along the aeroshell, 5) evaluation of manufacturing joint region yielding and 6) evaluation of nosetip dynamic fracture. Each of the above mentioned responses can be caused by terminal air blast, side-on hot X-ray thermal structural response (TSR) and/or side-on impulse from cold X-ray encounters.

(U) Large relative deflections of the components inside the RB can cause physical impact and cable crushing during vulnerability encounters. Excessive stresses produced in the RB components can cause loss of structural integrity (i.e., yield or failure).

(U) In the following sections a summary of the vulnerability assessment made for each candidate will be presented, including a statement of feasibility regarding the candidate's material and structural responses to the MK4A hostile environments.

8.4.1 (U) LL4-1a STRUCTURAL ASSESSMENT SUMMARY

8.4.1.1 (U) LL4-1a Design Description

b(3)
DOE
DTRA

b(3)
DOE
DTRA

FIGURE 8.4.1-1
(U) LL4-1a FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 8.4.1-2
(U) NEP COMPARISON

b(3)
DOE

FIGURE 8.4.1-3
(U) FORWARD WARHEAD SUPPORT

b(3)
DOE
DTRA

FIGURE 8.4.1-4
(U) AFT WARHEAD SUPPORT

b(3) DOE DTRA

The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE. The connector on the aft closure will require RF and thermal protection. Other than the addition of the connector on the aft closure its design remains very similar to the W76/MK4. Candidate mass properties (RB weight and CG location) are shown in Figure 8.2-2.

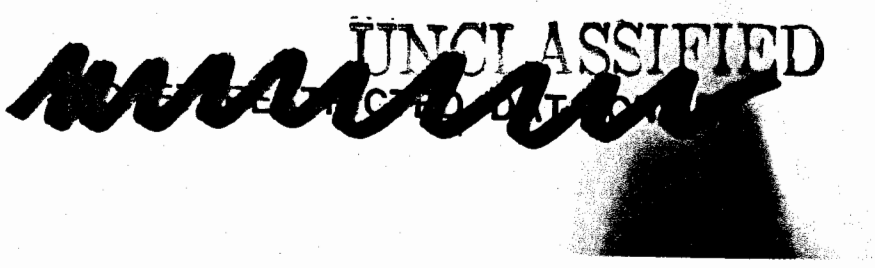
(U) For either the MK4/D5 or MK4/C4 RB configuration some modification to the RBA would be required to accommodate the use of an additional nuclear safety strong link. An additional 1 to 3 components would need to be mounted on the RA to activate and power the additional strong link. The MK4 IFD needs to be replaced by a MK5-size IFD insert (to accommodate the additional pins required for the safety components). New RB and RA cable assemblies would need to be fabricated.

(U) LL4-1a requires some forward ballasting to meet the mass property design space limit. This task can be accomplished by either DoD or DOE.

b(3) DOE DTRA

b(3)
DOE
DTR

FIGURE 8.4.1-5
(U) FWD SHELL MODIFICATION



8.4.1.2 (U) LL4-1a Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The LL4-1a concept was assessed early in the assessment period. The approach used to assess the LL4-1a concept was predicated on the design attributes of the forward warhead support and the aft warhead wedge support. (See Figure 8.4.1-1). The LL4-1a concept had a forward warhead support design similar to the MK4 tactical design. This area was assessed using existing MK4 capability curves. The aft warhead support wedge area was originally substantially different from the MK4 tactical design and was assessed using a Finite Element analysis. The seal cover design was similar to the MK4 tactical, although a programmer has been mounted to it. Given the similarity to MK4 the seal cover was assessed to be good by inspection. (See Figure 8.4.1-1). The warhead attach, the wedge, and the seal cover designs were assessed for the critical MK4 V–γ trajectories (upper middle-UM, max axial and max transverse).

(U) Assessment Results

(U) The assessment of the LL4-1a design reflected positive margins with the exception of the aft wedge which had a negative margin. This negative margin was caused by the smaller original wedge design that was located further forward than the MK4 tactical wedge. It was suggested and subsequently implemented that a longer wedge be included in the design and this was incorporated in the latest design.

8.4.1.3 (U) LL4-1a Hostile Reentry Structural Assessment

(U) As mentioned in the beginning of this section, the baseline designs for all six LL4-x candidates include an Advanced Heather gas transfer system, although Acorn and Heather gas systems were available for use. During the LMSC vulnerability assessment the baseline system was utilized in the full-up analyses for each of the candidates. LMSC evaluated the LL4-1a design to see if variations in the gas transfer system would significantly alter component response. It was found

that, for the weight variations seen between the three gas systems component responses were similar and therefore, the feasibility statement made for each of the baseline systems apply for all of the possible gas systems.

(U) Material Vulnerability Assessment

[redacted]

b(3)
DOE
DTR

(U) Structural Vulnerability Assessment

(U) The forward and aft warhead supports and the NEP of the LL4-1a concept were quite different from those of the MK4 baseline as seen in Figures 8.4.1-3 and 8.4.1-4. Issues important to structural vulnerability were the differences in the forward support Alvis joint connection (activated when the forward support is under tension during blast, TSR and impulse encounters), the aft support and the AF&F Support ring. For the aft support, the inner foam support in the W76/MK4 was eliminated due to a larger aft warhead radius. The outer foam wedge was used and is similar to the W76/MK4.

(U) A full-body finite element (DYNA3D) analysis was performed to assess the effects of blast, TSR and impulse forcings. The model used was the existing LMSC MK4 full-body DYNA3D model in which the model for the NEP and its support was replaced with a LLNL-supplied DYNA3D model for the LL4-1a NEP. Additional concentrated masses were added to the aeroshell model to simulate the ballast of 10 lbs. attached at the nose anvil (Figure 8.4.1-1). Also, modifications were

made to simulate the AF&F support ring. The interface accounts for sliding and gap opening, elasto-plastic behavior of metal parts and dynamic structural instability.

(U) The aft-on impulse and TSR load from the aft-on cold X-ray exposures were not analyzed, because, based on past MK4 test experience, their effect is felt mostly at the aft cover and is attenuated rapidly as it moves forward through the RB structure. Since the design in this region remains the same no analyses were needed.

(U) Assessment Results

(U) LL4-1a assessment results showed that the principal structural responses of peak stress, and deflection were acceptable for the blast, TSR and impulse forcings.

(U) Both low and high frequency responses for the critical aeroshell regions, as assessed by DYNA3D blast, TSR and impulse analyses, indicated that small increases occurred in the low-frequency response levels relative to W76/MK4 responses. These response increases, though, did not exceed the design allowables.

(U) Peak relative deflections seen at hardware interfaces were found to be driven by the blast environment. The most critical response was the relative axial deflection between the AF&F tip and the aeroshell substrate. Analysis showed that this deflection was less than the existing gap width and therefore, the design was considered acceptable. Cable crushing resulting from relative lateral deflections between the NEP and the inside surface of the substrate was also found to be less than the existing gap.

(U) Additionally, the peak stresses in the aeroshell substrate, forward support, Alvis joint and the aft foam support were all below allowables for blast, hot X-ray (TSR) and cold X-ray (impulse) loadings.

(U) Finally, the possibility of shell buckling was found not to be an issue with this candidate. This was confirmed for each loading by inspecting the deformation shape of the DYNA3D model at peak response times for any indication of buckling collapse.

8.4.1.4 (U) LL4-1a Candidate Feasibility Statement

(U) Analysis of the LL4-1a candidate was accomplished early in the assessment period and concluded that the design was feasible as proposed. During the assessment period modifications were made to the LL4-1a design by the DOE laboratories to improve its performance in normal, as well as hostile environments. These modifications included the addition of foam filler around the NEP, lengthening the aft warhead support and utilizing the W76/MK4-like preloads in the aft warhead support design. These updates have been reviewed with the result being that the LL4-1a candidate was assessed as feasible as proposed.

8.4.2 (U) LL4-1b STRUCTURAL ASSESSMENT SUMMARY

8.4.2.1 (U) LL4-1b Design Description

b(3) DOE DTRA

(U) This concept is almost identical to LL4-1a with the exception of the new AF&F. In order to accommodate the new AF&F the anvil on the inside front end of the substrate must be removed. See Figure 8.4.2-2. The new AF&F radar may not be compatible with the existing W76/MK4 antenna system and would require further evaluation. This design also utilizes a PEX Booster which is incorporated in the new AF&F.

(U) The NEP is identical to LL4-1a without exception. Thus the forward and aft warhead supports are identical to LL4-1a. The seal cover is also identical to LL4-1a.

(U) Use control capability and material concerns are identical to that of LL4-1a. Safety-related component and cabling issues are also identical to that of LL4-1a. The mass properties (RB weight and CG location) of this design are shown in Figure 8.2-2.

b(3)
DOE
DTRA

FIGURE 8.4.2-1
(U) LL4-1b FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 8.4.2-2
(U) NEP COMPARISON

b(3)
DOE
DTRA

b(3)
DOE
DNA

FIGURE 8.4.2-4
(U) AFT WARHEAD SUPPORT

(U) Any ballasting required will be incorporated in the new AF&F. All DoD forward ballasting capability (see the LL4-1a assessment) has been replaced by the new AF&F (Figure 8.4.2-5).

(U) As in LL4-la, MK4/D5 and MK4/C4 RAs will also need to be modified to accommodate the added safety related components. Like LL4-1a, the proposed CAT-E PAL use control capability is feasible and the concept is compatible with all the missile physical and functional interfaces. Housing the additional safety components on the RA is feasible and will require structural modification to the RAs.

8.4.2.2 (U) LL4-1b Normal Reentry Structural Assessment

(U) Analysis Approach and Results

(U) LL4-1a and b, LL4-2a and b and LL4-3a and b candidates have been grouped because of their commonality in design and have been assessed as one configuration. See Section 8.4.1.2.

8.4.2.3 (U) LL4-1b Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

(U) The design differences of the LL4-1b and the LL4-1a do not affect this response. Therefore the conclusion for LL4-1b is the same as for LL4-1a which was acceptable. See Section 8.4.1.3..

(U) Structural Vulnerability Assessment

(U) The LL4-1b analysis used the same full-body finite element (DYNA3D) model of LL4-1a modified to reflect the additional 5.2 lbs of weight and the slightly forward CG position of the new AF&F in LL4-1b. The same critical regions and loadings were examined for LL4-1b as for LL4-1a. The results showed that the general responses were below allowables, although the most critical response, the substrate stress in the forward frustum, has small local yielding. Design feasibility should be attainable, as further studies would identify specific design solutions.

b(3)
DOE
DTRA

FIGURE 8.4.2-5
(U) AF&F COMPARISON

UNCLASSIFIED

b(3)
DOE
DTRA

FIGURE 8.4.3-1
(U) LL4-2a FULL BODY PROFILE

UNCLASSIFIED

b(3)
DoE
DTRA

FIGURE 8.4.3-2
(U) NEP COMPARISON

UNCLASSIFIED

b(3)
DOE
DTRA

FIGURE 8.4.3-3
(U) FORWARD WARHEAD SUPPORT

UNCLASSIFIED

b(3)
DOE
DTRA

FIGURE 8.4.3-4
(U) AFT WARHEAD SUPPORT

of the connector on the aft closure its design remains very similar to the W76/MK4. Candidate mass properties (RB weight and CG location) of this design are shown in Figure 8.2-2.

(U) For either the MK4/D5 or MK4/C4 RB configuration some modification to the RBA would be required to accommodate the use of an additional nuclear safety strong link. An additional 1 to 3 safety-related components would need to be mounted on the RA to activate and power the additional strong link. The MK4 IFD needs to be replaced by a MK5-size IFD insert (to accommodate the additional pins required for the safety components). New RB and RA cable assemblies would need to be fabricated.

(U) Like LL4-1a, LL4-2a requires some forward ballasting to meet the mass properties limits mentioned in Section 8.2. This task can be accomplished by either DoD or DOE.

(U) This design is not fully compatible with existing DoD hardware and will require some changes to the existing AF&F shielding for forward ballasting and both the MK4/D5 and MK4/C4 RAs for mounting added safety components. The proposed CAT-E PAL use control capability is feasible and the concept is compatible with all the missile physical and functional interfaces. Housing the additional safety components on the RA is feasible and will require structural modification to the RAs. Forward ballasting will require changes to existing DoD and DOE hardware (see LL4-1a assessment).

8.4.3.2 (U) LL4-2a Normal Reentry Structural Assessment

(U) Analysis Approach and Results

(U) LL4-1a and b, LL4-2a and b, and LL4-3a and b candidates have been grouped because of their commonality in design and have been assessed as one configuration. See Section 8.4.1.2.

8.4.3.3 (U) LL4-2a Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

b(3)
DOE
DTRA

(U) Structural Vulnerability Assessment

(U) The structural response of the LL4-2a was expected to be similar to that of LL4-1a, as well. According to LLNL's information, the stiffness and mass distribution of LL4-1a should be used for the LL4-2a evaluations, even though the warhead contour is different at the forward end. In addition, the forward support stiffness/strength of LL4-1a can be duplicated in LL4-2a because sufficient space exists to arrive at such a design.

8.4.3.4 (U) LL4-2a Candidate Feasibility Statement

(U) The feasibility of LL4-2a (Figure 8.4.3-1) candidate design was assessed in reference to LL4-1a because of design similarity and the common stiffness and mass distribution data received. A longer forward mount was used in LL4-2a to reach the forward portion of the warhead because it was smaller than the LL4-1a design. This candidate was evaluated to be feasible as proposed.

8.4.4 (U) LL4-2b STRUCTURAL ASSESSMENT SUMMARY

8.4.4.1 (U) LL4-2b Design Description

b(3)
DOE
DTRA

b(3)
DOE
DTRA

FIGURE 8.4.4-1
(U) LL4-2b FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 8.4.4-2
(U) NEP COMPARISON

UNCLASSIFIED

b(3)
DOE
DTRA

FIGURE 8.4.4-3
(U) FORWARD WARHEAD SUPPORT

b(3)
DOE
DTRA

FIGURE 8.4.4-4
(U) AFT WARHEAD SUPPORT

(U) This concept is almost identical to LL4-2a with the exception of the new AF&F. In order to accommodate the new AF&F the anvil on the inside front end of the substrate was removed. The new AF&F radar may not be compatible with the existing W76/MK4 antenna system and would require further evaluation. This design also utilizes a PEX Booster which is incorporated in the new AF&F.

(U) The NEP is identical to LL4-2a without exception. Thus the forward and aft warhead supports are identical to LL4-2a. The seal cover is also identical to LL4-2a.

(U) Use control capability and material concerns are identical to that of LL4-2a. Safety-related component and cabling issues are also identical to that of LL4-2a. The mass properties (RB weight and CG location) of this design are shown in Figure 8.2-2.

(U) Any ballasting required will be incorporated in the new AF&F. All DoD forward ballasting capability (see the LL4-1a assessment) has been replaced by the new AF&F.

(U) As in LL4-1a, MK4/D5 and MK4/C4 RAs will also need to be modified to accommodate the added safety related components. Like LL4-1a, the proposed CAT-E PAL use control capability is feasible and the concept is compatible with all the missile physical and functional interfaces. Housing the additional safety components on the RA is feasible and will require structural modification to the RAs.

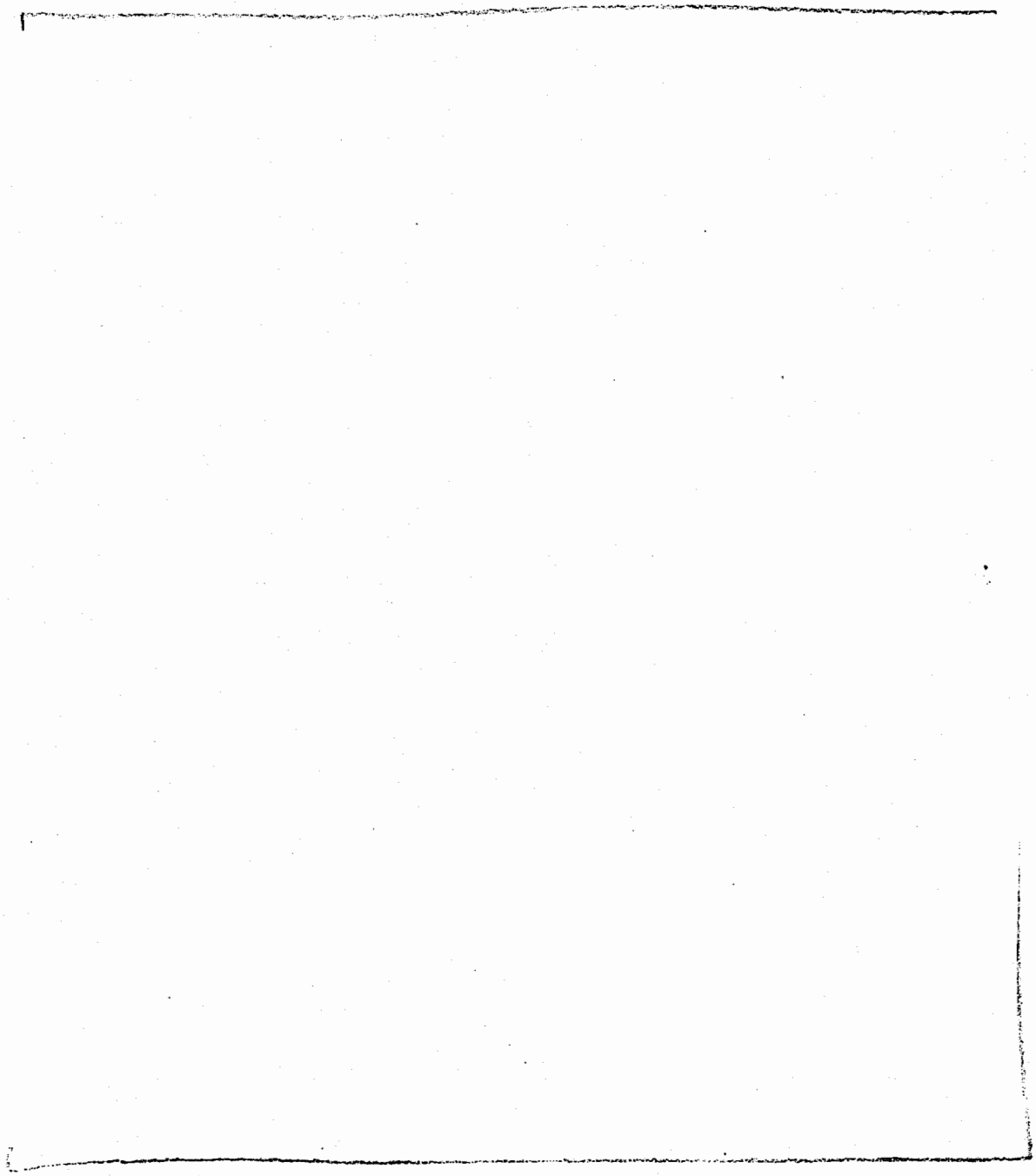
8.4.4.2 (U) LL4-2b Normal Reentry Structural Assessment

(U) Analysis Approach and Results

(U) LL4-1a and b, LL4-2a and b, and LL4-3a and b candidates have been grouped because of their commonality in design and have been assessed as one configuration. See Section 8.4.1.2.

b(3)
DoE
DTRA

FIGURE 8.4.5-1
(U) LL4-3a FULL BODY PROFILE



b(3)
DOE
DTRA

FIGURE 8.4.5-2
(U) NEP COMPARISON

b(3)
DOE
DTRA

FIGURE 8.4.5-4
(U) AFT WARHEAD SUPPORT

b(3) DOE DTRA

The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE.

b(3) DTRA

Other than the addition of the connector on the aft closure its design remains very similar to the W76/MK4. Candidate mass properties (RB weight and CG location) of this design are shown in Figure 8.2-2.

(U) For either the MK4/D5 or MK4/C4 RB configuration some modification to the RBA would be required to accommodate the use of an additional nuclear safety strong link. An additional 1 to 3 components would need to be mounted on the RA to activate and power the additional strong link. The MK4 IFD needs to be replaced by a MK5-size IFD insert to accommodate the additional pins required for the safety components. New RB and RA cable assemblies would need to be fabricated.

(U) Like LL4-1a, LL4-3a requires some forward ballasting to meet the mass properties limit described in Section 8.2. This task can be accomplished by either DoD or DOE.

b(3) DOE DTRA

Housing the additional safety components on the RA is feasible but will require structural modification to

the RAs.

b(3) DOE STRA

8.4.5.2 (U) LL4-3a Normal Reentry Structural Assessment

(U) Analysis Approach and Results

(U) LL4-1a and b, LL4-2a and b, and LL4-3a and b candidates have been grouped because of their commonality in design and have been assessed as one configuration. See Section 8.4.1.2.

8.4.5.3 (U) LL4-3a Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

(U) Early time material responses will not be significantly affected by the design differences between the LL4-3a and the LL4-1a. Therefore, no additional material vulnerability concerns were identified.

(U) Structural Vulnerability Assessment

(U) The late-time structural response of this candidate was assessed to be similar to LL4-1a because the stiffness and mass distribution of LL4-1a NEP were provided for use in assessing the LL4-3a candidate. Therefore, by analogy to the feasible LL4-1a design, the LL4-3a design is also feasible as proposed.

8.4.5.4 (U) LL4-3a Candidate Feasibility Statement

(U) The feasibility of the LL4-3a candidate design was assessed in reference to the LL4-1a because of design similarity and the common stiffness and mass distribution data received. These two designs are identical except for some differences in warhead or NEP internals. The results of the assessment were a feasible as proposed evaluation.

8.4.6 (U) LL4-3b STRUCTURAL ASSESSMENT SUMMARY

8.4.6.1 (U) LL4-3b Design Description

(3)
DOE
DTRA

(U) Note that this concept is almost identical to LL4-3a with the exception of the new AF&F. In order to accommodate the new AF&F the anvil on the inside front end of the substrate was removed. The new AF&F radar may not be compatible with the existing W76/MK4 antenna system and will require further assessment. This design also utilizes a PEX Booster which is incorporated in the new AF&F.

(U) The NEP is identical to LL4-3a without exception. Thus the forward and aft warhead supports are identical to LL4-3a. The seal cover is also identical to LL4-3a.

(U) Use control capability and material concerns are identical to that of LL4-3a. Safety-related component and cabling issues are also identical to that of LL4-3a. The mass properties (RB weight and CG location) of this design are shown in Figure 8.2-2.

(U) Any ballasting required will be incorporated in the new AF&F. All DoD forward ballasting capability (see the LL4-1a assessment) has been replaced by the new AF&F.

(U) This design may be not fully compatible with the existing DoD hardware depending on the radar selected. Like LL4-1b, the new AF&F radar compatibility with the existing W76/MK4 antenna system will need to be assessed when more detailed design information is available. As in LL4-3a, MK4/D5 and MK4/C4 RAs will need to be modified to accommodate the added safety related components. The forward aeroshell also needs to be modified to accommodate the new AF&F (the forward ballast would be incorporated into DOE components). Like LL4-3a, the proposed CAT-E PAL use control capability is feasible and the concept is compatible

b(3)
DOE
DTRA

FIGURE 8.4.6-1
(U) LL4-3b FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 8.4.6-2
(U) NEP COMPARISON

b(3)

DOE
DTRA

FIGURE 8.4.6-3
(U) FORWARD WARHEAD SUPPORT

[redacted] UNCLASSIFIED

b(3)

DOE
DTRA

FIGURE 8.4.6-4
(U) AFT WARHEAD SUPPORT

8.4.7 (U) LA4-1 STRUCTURAL ASSESSMENT SUMMARY

8.4.7.1 (U) Design Description

b(3) DOE DTRA

The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE.

b(3) DTRA

b(3) DOE DTRA

8.4.7.2 (U) LA4-1 Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The LA4-1 design was assessed by engineering judgment based on limited details of a 8 1/2 x 11 layout shown in the "Excerpts from the Fourth SLBM Phase 2 Study Group", dated 4 March 1993. The forward warhead attachment is that of the MK4 design and the aft wedge support and the seal cover designs are similar to the MK4 design.

b(3)
DOE
DTRA

FIGURE 8.4.7-1
(U) LA4-1 FULL BODY PROFILE

b(3)
DOE
DTRA

FIGURE 8.4.7-2
(U) NEP COMPARISON

b(3)
DOE
DTRA

FIGURE 8.4.7-3
(U) FORWARD WARHEAD SUPPORT

[redacted]

indicate that the design for the forward warhead attach, the aft wedge supp[illegible] and the seal cover would produce positive margins of safety.

8.4.7.3 (U) LA4-1 Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

b(3)
DOE
DTRA

(U) Structural Vulnerability Assessment

(U) The LA4-1 candidate has many design features which are similar to the W76/MK4. For this reason some of the sensitivity study analysis results which were performed using the MK4 aeroshell during the early portion of Phase 2 are applicable in assessing LA4-1. In these sensitivity studies the stiffness of the warhead and warhead attach points were varied, as was the weight of the NEP allowing the analyst to evaluate the effect of each variable on system performance. Given that the LA4-1 and W76/MK4 forward and aft warhead supports are nearly identical, and that the NEP change was not large, it was felt that the structural responses of the LA4-1 design would remain within the allowable limits.

8.4.7.4 (U) LA4-1 Candidate Feasibility Statement

(U) Analysis of the LA4-1 candidate design was accomplished utilizing a conceptual drawing and general mass property information. While this may be closer to a true Phase 2 type of assessment it is still considerably less information than has been received for many of the other candidates and has much larger uncertainties associated with the assessment conclusions. With these caveats in mind the LA4-1 design was assessed to be feasible due to its similarity to the W76/MK4.

8.4.8 (U) LA4-2 STRUCTURAL ASSESSMENT SUMMARY

8.4.8.1 (U) Design Description

b(3) DOE DTRA

The required interface is accomplished by the addition of through connectors on the seal cover and aft closure with an interconnecting cable. The connectors and cable are the responsibility of the DOE.

b(3) DTRA

Other than the addition of the connector on the aft closure its design remains very similar to the W76/MK4.

b(3) DOE

This task can be accomplished by either DoD or DOE.

(U) The proposed CAT-E PAL use control capability is feasible. Forward ballasting will require changes to existing DoD and DOE hardware. This task will entail modifying the anvil for mounting the ballast and a new DOE radiation shield to fit in the remaining volume.

8.4.8.2 (U) LA4-2 Normal Reentry Structural Assessment

(U) Analysis Approach

(U) The LA4-2 design was assessed by engineering judgment based on limited details of a 8 1/2 x 11 layout shown in the "Excerpts from the Fourth SLBM Phase 2 Study Group", dated 4 March 1993. The forward warhead attach and the seal cover are similar to the W76/MK4 design configuration. The aft wedge is thinner and

(3)
DOE
DTRA

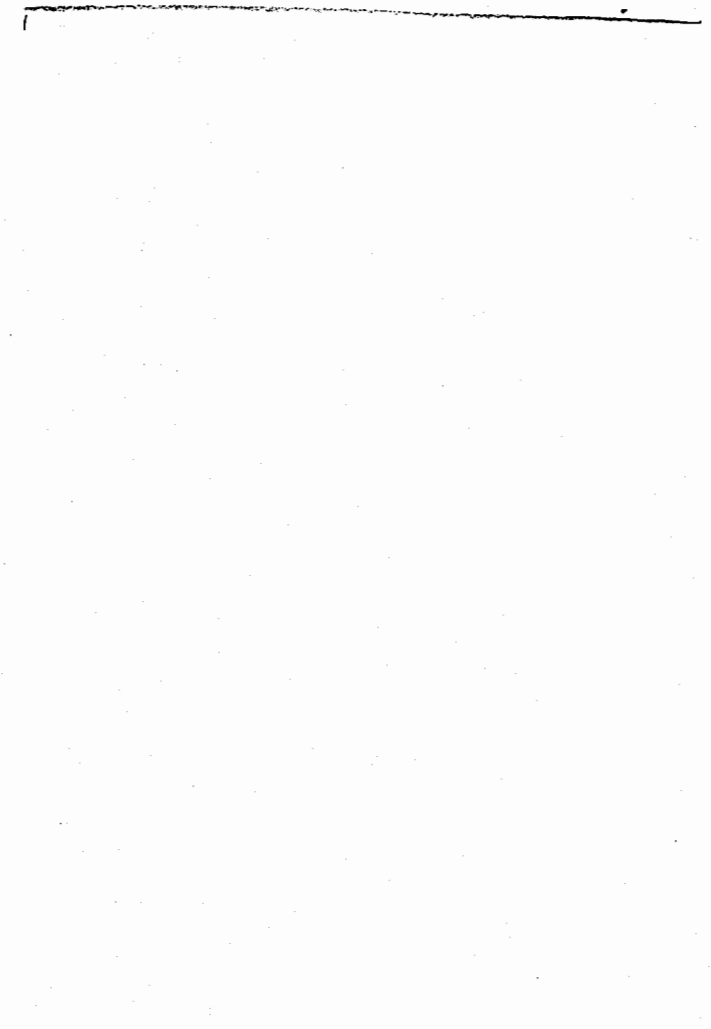


FIGURE 8.4.8-1
(U) LA4-2 FULL BODY PROFILE

[redacted]

b(3)
DOE
DTRA

FIGURE 8.4.8-4
(U) AFT WARHEAD SUPPORT

has approximately the same length as the W76/MK4, but has a forward slant at the wedge/warhead interface. This forward slant will require a gap at the wedge/warhead interface to allow for axial thermal expansion, otherwise the aeroshell will be locked at the forward warhead attach point and the wedge area, which will introduce large stresses in the aeroshell and forward wedge areas. Neither the gap nor the locked aeroshell are considered desirable conditions.

(U) Assessment Results

(U) The initial assessment of the LA4-2 based on the 8 1/2 x 11 layout would indicate that a design for the forward warhead attach area and the seal cover would produce positive margins of safety. The aft wedge design could result in high stresses in both the wedge and the aeroshell.

8.4.8.3 (U) LA4-2 Hostile Reentry Structural Assessment

(U) Material Vulnerability Assessment

b(3)
DOE
DTRA

(U) Structural Vulnerability Assessment

(U) The LA4-2 candidate has some design features which are similar to the LL4-1a, which was assessed to be feasible. Two structural design issues were noted in the assessment of the LA4-2 candidate. First, the aft warhead support was found to be thinner than the W76/MK4 support. Second, the forward warhead support appears to need strengthening in order to withstand the hostile environment encounters.

Both of these design differences involve a reduction in component size (relative to W76/MK4) which would require more analysis to determine actual structural responses.

8.4.8.4 (U) LA4-2 Candidate Feasibility Statement

(U) Analysis of the LA4-2 candidate design was accomplished utilizing a conceptual drawing and general mass property information. This is considerably less information than has been received for many of the other candidates and as such, has much larger uncertainties associated with the assessment conclusions. With these caveats in mind the LA4-2 design was assessed to be feasible with potential modifications to the forward warhead support. The slanted aft wedge design feature may need to be modified to reduce aeroshell stresses.

9. EFFECTIVENESS

presented to all working group members to review. This method added robustness to the study, by considering a greater number of analysis possibilities than if all members used the same assumptions.

9.1.3. (U) EFFECTIVENESS RESULTS SUMMARY

(U) The yields and weights of the W76/MK4, W88/MK5, and candidate warheads are shown in decreasing yield in Table 9-1 below, along with a comparative effectiveness ranking and rating.

9.1.3.1. (U) MK4A Effectiveness Summary

b(3). DOE DTRA

9.1.3.2. (U) MK5A Effectiveness Summary

b(3) DOE DTRA

TABLE 9-1
(U) SLBM PHASE 2 WARHEAD CANDIDATES AND EFFECTIVENESS RANKINGS

b(3)
DOE
DTAA

9.2. (U) GROUND RULES AND ASSUMPTIONS

(U) The SPETWG generally followed all the ground rules and assumptions contained in the Technical Objectives and Guidelines (TOG) for this study. The SPETWG also used the additional ground rules and assumptions in Sections 9.2.1.1 through 9.2.1.5.

9.2.1. (U) MISSILE CHARACTERISTICS AND CAPABILITIES

9.2.1.1. (U) Range / Payload Performance

(U) Figures 9-1, 9-2, and 9-3 show the range/payload assumptions used for this study and are based on data provided by LMSC. Figure 9-1 shows the range/payload capabilities for the W76/MK4 on the C4 missile. Figures 9-2 and 9-3 show the capabilities for the W76/MK4 and W88/MK5 respectively on the D5 missile. Using the weights of the candidates and the weight-to-range tradeoffs shown, the SPETWG determined the range/payload capabilities for MK4A candidates on both the C4 and D5 missiles and for MK5A candidates on the D5 missile.

9.2.1.2. (U) Weapon System Accuracy

The SPETWG used weapon accuracy values for D5 and C4 missiles based upon May 1993 TRIDENT CINCEVAL accuracy projections prepared by TASC. The D5 missile weapon system accuracy is shown as a function of range in Figure 9-4.

b(3) DOE DTRA

9.2.1.3. (U) Footprinting Capability

The footprint capabilities of each of the candidates used in developing effectiveness results are based on LMSC data.

b(3) DTRA

For example, with a payload

b(3) DOE DTRA

b(3)
DIA

FIGURE 9-1
(U) C4/MK4 RANGE/PAYLOAD CONFIGURATIONS

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FIGURE 9-2
(U) D5/MK4 RANGE/PAYLOAD CONFIGURATIONS

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DOE
DTRA

FIGURE 9-3
(U) D5/MK5 RANGE/PAYLOAD CONFIGURATIONS

UNCLASSIFIED

b(3)
DOE
DTRA

FIGURE 9-4
(U) ACCURACY VERSUS RANGE FOR D5 MISSILE

b(3)
DE
DTRA

FIGURE 9-5
(U) ACCURACY VERSUS RANGE FOR C4 MISSILE

b(3) DOE DTRA

9.2.1.4. (U) Heights of Burst Fuzing Options

The SPETWG assumed that the HOBs of a MK4A would be changed from those of the W76/MK4.

b(3) DOE DTRA

9.2.1.5 (U) Reliability

In the force level effectiveness analysis, one study assumed a weapon system reliability (WSR) of 0.89 for all missiles, regardless of the type of warhead carried. Otherwise, the SPETWG did not consider reliability issues in the rest of their effectiveness assessments.

9.2.2. (U) FORCE UTILIZATION

9.2.2.1. (U) Force Levels and Missile Configurations

b(3) DTRA

The results from the other cases did not change the conclusions drawn from the 14 TRIDENT II (D5) case and are not presented in this report.

TABLE 9-2
(U) FORCE CONFIGURATIONS

b(3) DOE DTRA

9.2.2.2. (U) Operating Areas and SSBN Deployments

b(1) DTRA

The Aleutian Island chain and the Greenland-Iceland-United Kingdom gap formed effective northern barriers to these operating areas. Some of the assessments performed in this study used large fractions of these operating areas, and other assessments focused on those parts of the operating areas closest to the target base.

9.2.3. (U) TARGET BASES

(U) Each analyst in the SPETWG developed his own target bases, according to the scenarios he was analyzing. The target bases of the different analysts had many similarities and some differences. Each analyst developed a target base in Russia and a target base in China, but the Russian target bases, being harder and more diverse, had the most influence on the analyses.

One target base used in this study representative of the START II target base is

b(1) DTRA

b(1)
DTRA

9.2.3.1. (U) Treaty and Force Configuration Scenarios

(U) The base-case scenarios assumed that the START II treaty, negotiated by Presidents Bush and Yeltsin, would become effective. However, the SPETWG also assessed cases where only the START I agreement would become effective. The SPETWG performed no specific analyses in which they assumed that both START treaties would be rejected.

9.2.3.2. (U) Damage Mechanisms

(U) For many of the effectiveness comparisons, the single-shot probability of kill (SSPK) is the primary MOE considered. The damage mechanism assumed for SSPK is air blast overpressure causing severe structural damage to the facility, as defined by the DIA's Physical Vulnerability Handbook for Nuclear Weapons (OGA-2800-23-92). For this damage mechanism, an air burst is the appropriate fuze option, and each warhead candidate was evaluated using its most effective fuze option. For MK4A candidates, the radar fuze with optimum HOBs was used. For MK5A candidates, the radar-updated path length (RUPL) fuze with optimum HOBs was used

9.3. (U) APPROACH AND METHODOLOGY

9.3.1. (U) MEASURES OF EFFECTIVENESS

(U) The SPETWG defined nine different measures of effectiveness (MOEs) for MK4A and MK5A (Table 9-3), each of which addressed a specific aspect of effectiveness.

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TABLE 9-3

(U) MEASURES OF EFFECTIVENESS

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9.3.1.1. (U) MK4A Measures of Effectiveness

9.3.1.1.1. (U) *SSPK Against 27P0 Target on C4*

The SPETWG calculated the SSPK of each candidate against a target with a vulnerability number (VNTK) of 27P0.

b(3) DOE DTRA

When the W76/MK4 was developed, the weapon system CEP was such that this type of target was considered difficult to successfully attack. With the improvements in CEP experienced by the C4 missile, this target is no longer the challenge it once was. Nevertheless, the SPETWG considered it to be an important MOE for this system, and used it in their analyses.

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b(3)
DOE
DTRA

FIGURE 9-7
(U) MK4A SSPK FOR A 27P0 TARGET ON C4

9.3.1.1.2. (U) *SSPK Against 46L8 Target on D5*

The SPETWG also calculated the SSPK of the MK4A candidates on a D5 missile against a hard target.

b(3)
DOE
DTRA

Figure 9-8 shows the values of this MOE for each of the candidates.

b(3)
DOE
DTRA

FIGURE 9-8
(U) MK4A SSPK FOR 46L8 TARGET ON D5

9.3.1.1.3. (U) *Average SSPK for Potential MK4A Target Set*

[redacted] The SPETWG calculated the average SSPK across the total set of potential MK4 targets softer than VNTK 46L8. This represents a set of targets likely to be eligible for the MK4A. Figure 9-9 shows the values of this MOE for each of the candidates.

b(3)
DOE
DTRA

FIGURE 9-9
(U) MK4A AVERAGE SSPK

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[redacted]

b(3) DTRA

9.3.1.1.4. (U) *Fraction SSPK*

[redacted] The SPETWG calculated the fraction of potential MK4 targets that are softer than 46L8[redacted] This MOE provides a concise measurement of how much of the target base is held at risk. Figure 9-10 shows the values of this MOE for each of the candidates.

b(3) DTRA

b(3) DOE DTRA

9.3.1.1.7. (U) *Number of DGZs Required to Cover Target Base*

[redacted] The SPETWG compared the numbers of DGZs (Designated Ground Zeros, or aimpoints) that would be required for each MK4A candidate to cover, or attack, a START II target base in Russia. Weapons requiring fewer DGZs to cover the target base would be more effective than those requiring more DGZs.

b3 DTRA

b(3) DOE DTRA

The SPETWG methodology associates with a given DGZ those target installations that are close enough to the DGZ that the minimum SSPK for installations offset from the actual aimpoint, PKmin(offset), would be not less than [redacted] DGZ development is insensitive to CEP and PKmin(offset), but it is sensitive to yield. Thus these resulting MOEs decreased monotonically as yield decreased, with a [redacted] swing in numbers of DGZs required from the highest to the lowest candidate yield. Figure 9-13 shows the values of this MOE for each of the candidates.

b(3) DTRA

b(3) DOE DTRA

FIGURE 9-13
(U) MK4A NUMBER OF DGZS REQUIRED

9.3.1.1.8. (U) *Weighted Worth Damaged in Strike*

(U) The SPETWG calculated the effectiveness of various strike plans developed by SPETWG analysts using MK4A RBs against Russian target bases. Different kinds of target installations were assigned different relative values by the various analysts, and the overall effectiveness of the strikes were assessed as a percentage of the weighted worth of the total target base damaged in those strikes. In these assessments, strike effectiveness was calculated using CEPs that depended on the range of the target installations from the assumed launch points. Choices of target bases, target-worth weightings, and missile launch points all varied from analyst to analyst. Even so, the results were close enough that the SPETWG was able to arrive at a single set of values representing this measure of effectiveness. This measure of effectiveness proved insensitive for MK4A comparisons, varying by only 5 per cent. Figure 9-14 shows this MOE for each of the candidates.

b(3)
DOE
DTRA

FIGURE 9-14
(U) MK4A WEIGHTED WORTH DAMAGED IN STRIKE

9.3.1.1.9. (U) *Damage to Other Military Targets*

(U) Finally, the SPETWG calculated the effectiveness of various strike plans developed by SPETWG analysts against Russian target bases. The effectiveness of these overall strike plans in attacking that subset of the target base identified as Other Military installations was calculated. The SPETWG believes that Other

9.3.1.1.10. (U) *Summary of MK4A MOE Values*

(U) A summary of the MOE values and relative scores for the MK4A is given in Table 9-4.

TABLE 9-4
(U) MEASURE OF EFFECTIVENESS VALUES FOR MK4A

b(3)
DOE
DTRA

9.3.1.2. (U) MK5A Measures of Effectiveness

(U) In addition, the SPETWG defined nine MOEs for the MK5A candidates (see Table 9-3).

9.3.1.2.1. (S) *SSPK Against 52L7*

(S) The SPETWG calculated the SSPK of each candidate against a target with a VNTK of 52L7.

b(3)
DOE
DTRA

When the W88/MK5 was developed, this was the assessed VNTK of the hardest Soviet silos. Although those SS-18 silos have since been assessed to be much harder than 7000 psi, the SPETWG considers 52L7 to be a significant figure of effectiveness for this system because of the history of its use. The was used, and the results varied monotonically with yield, with a

b(3)
DTRA

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b(3) DOE DTRA

FIGURE 9-17
MK5A SSPK AGAINST 64L9 TARGET

b(3) DOE DTRA

FIGURE 9-18
MK5A AVERAGE SSPK (U)

b(3) DTRA

9.3.1.2.4. (U) *Fraction SSPK*

The SPETWG calculated the fraction of MK5A targets that are harder than 46L8 and where This MOE is one estimate of how much of the MK5A target base is held at risk. Differences in this MOE between specific candidates can be very sensitive to the assumed hardness and SSPK

b(3) DTRA

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b(3)
DOE
DTRA

FIGURE 9-21
(U) MK5A FOOTPRINTING EFFICIENCY

9.3.1.2.7. (U) *Number of DGZs to Cover Target Base*

The SPETWG compared the numbers of DGZs (Designated Ground Zeros, or aimpoints) that would be required for each MK5A candidate to cover, or attack, a START II target base in Russia. Weapons requiring fewer DGZs to cover the target base would be more effective than those requiring more DGZs. The target base used in this particular calculation included [redacted] classified as Strategic Military, [redacted] categorized as Other Military, [redacted] categorized as National Leadership, and [redacted] categorized as War-Supporting Industry. The Strategic Military installations included only the numbers and types of ICBM silos permitted by the START II treaty.

b(1)
DTRA

b(3)
DOE
DTRA

[redacted] The SPETWG methodology associates with a given DGZ all target installations that are close enough to the DGZ that the minimum SSPK for all installations offset from the actual aimpoint, PKmin(offset), would be not less than [redacted] DGZ development is insensitive to CEP and PKmin(offset), but it is sensitive to yield. Thus these resulting measures of effectiveness decreased monotonically as yield decreased. Candidate yields for the MK5A in this study ranged from [redacted] Because of the dispersed nature of the target bases used in this study, this figure of merit varied by only about 10 per cent. Figure 9-22 shows the values of this MOE for each of the candidates.

b(3)
DTRA

b(3)
DTRA

b(3)
DOE
DTRA

FIGURE 9-22
(U) MK5A NUMBER OF DGZS REQUIRED

9.3.1.2.8. (U) *Weighted Worth Damaged in Strike*

(U) The SPETWG calculated the effectiveness of various strike plans developed by SPETWG analysts using MK5A RBs against Russian target bases. Different kinds of target installations were assigned different relative values by the various analysts, and the overall effectiveness of the strikes were assessed as a percentage of the weighted worth of the total target base damaged in those strikes. In these assessments, strike effectiveness was calculated using CEPs that depended on the range of the target installations from the assumed launch points. Choices of target bases, target-worth weightings, and missile launch points all varied from analyst to analyst. Even so, the results were close enough that the SPETWG was able to arrive at a single set of values representing this MOE. This MOE was monotonic with yield, and there was a 25 per cent swing in the values that are shown in Figure 9-23.

b(3)
DOE
DTRA

FIGURE 9-23
(U) MK5A WEIGHTED WORTH DAMAGED IN STRIKE

9.3.1.2.9. (U) *Damage to Strategic Military Targets*

(U) Finally, the SPETWG calculated the effectiveness of various strike plans developed by SPETWG analysts against Russian target bases. The effectiveness of these overall strike plans in attacking that subset of the target base identified as Strategic Military installations was calculated. The SPETWG thought that Strategic Military would be an important target set for MK5A weapons. In these assessments, strike effectiveness was calculated using CEPs that depended on the range of the target installations from the assumed launch points. Choices of target bases, designations of particular installations as falling into the Strategic Military category, and missile launch points all varied from analyst to analyst. Even so, the results were close enough that the SPETWG was able to arrive at a single set of values representing this MOE. Due to the large variation in the yields of the various candidates, there was a 30 per cent swing in the values that are shown in figure 9-24.

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b(3)
DOE
DTRA

FIGURE 9-24
(U) MK5A DAMAGE TO STRATEGIC MILITARY TARGETS

9.3.1.2.10. (U) *Summary of MK5A MOE Values*

(U) A summary of the MOE values and relative scores for the MK5A is given in Table 9-5.

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TABLE 9-5
(U) MEASURE OF EFFECTIVENESS VALUES FOR MK5A

b(3)
DoE
DTRA

9.3.1.3. (U) Decision Analysis Tools

9.3.1.3.1. (U) *Computational Techniques*

(U) Each analyst used his own calculational techniques and tools to study some or all the MOEs that the SPETWG used. Different analysts felt that certain MOEs were more important than others and combined them in ways resulting in different overall scores. In addition, combinations of MOEs and different relative weighting schemes were studied considering possible arms control treaty scenarios.

(U) Since each analyst used his own data bases, there were small differences between values calculated by different analysts for such MOEs as damage to Other Military targets and damage to Strategic Military targets. In addition, each analyst used his own relative-weighting scheme to value the various types of target installations, thus adding yet another dimension to the assessments of weighted worth damaged in a strike. Once all the calculations had been performed, the analysts compared the various calculational results and derived a set of final numbers to be used in the overall comparisons of candidates. The SPETWG believes this method of comparing diverse techniques and tools offered robustness to the assessments.

9.3.1.3.2. (U) *Analytical Spreadsheet Models*

(U) Two different spreadsheet-based tools were used to combine the many individual calculations into an overall assessment of relative effectiveness.

(U) ROMA

(U) The ROMA (Relative Overall Merit Assessment) spreadsheet calculates an overall effectiveness score by linearly adding the scores of each of the MOEs for each of the candidates in a weighted fashion. The result is then expressed in a normalized value with the W76/MK4 or W88/MK5 having a score of one. The MOE weights used in the overall score reflect the relative importance assigned by the SPETWG consensus and by individual analysts.

(U) WESVA

(U) The WESVA (Weapon Safety Value Assessment) spreadsheet model provides a method for aggregating selected MOEs into a single number called "total military value." The WESVA approach considers how performance penalties on one MOE compare in importance to penalties on the other MOEs, and whether a severe enough penalty on any particular MOE can essentially nullify any value provided by the other MOEs.

9.3.1.3.3. (U) *Force Analyses Methodology*

(U) The SPETWG performed a number of force effectiveness analyses to help assess the relative contributions of the various candidates to the overall effectiveness of an SSBN/SLBM force. Various analysts calculated the effectiveness of various strike plans that they developed using both MK4A and MK5A RBs against selected target bases. The results of all the analysis approaches described here are consistent with the overall conclusions of the study.

(U) One model developed by the SPETWG determined an allocation of warheads for a given distribution of FBM forces using a particular target database and submarine patrol areas. The correct range dependent CEP and weight-dependent maximum-range cutoff was used in determining target accessibility and damage capability for a given set of MK4 and MK5 warhead parameters (yield and weight) and force mix (numbers of C4 and D5 available for an attack). Pseudo-footprinting was used in that each target set was sorted into geographic grid cells that are the approximate size of the missile footprinting capability. Three target databases were used for this analysis. Two covered Russia, under two different arms control agreements (START I and Bush/Yeltsin[1]), and one covered China. The Chinese database was used for studying the effects of range capability on force disposition for

[1](S) The arms control negotiations for START II were underway while this study was being conducted. Independent positions on START II were established by Presidents Bush and Yeltsin early in 1992. These positions were used for the formation of the "Bush/Yeltsin" target database. The eventual agreement, reached at a later date, established levels somewhat different than the Bush/Yeltsin target database assumed and it represents a softer target database with 154 fewer SS-18 silos remaining. This is why the second target database is referred to here as Bush/Yeltsin and not START II.

a target set different from a Russian one, especially for potential use in hostile third world areas.

(U) For other force level assessments, each analyst assumed an overall SSBN force, a force at sea with specific numbers of RBs per SLBM, and a specific set of target installations, usually with more target installations than could be attacked by the assumed SSBN/SLBM force. Most of the analysts considered different sets of launch points within the assumed operating areas and used range dependent CEPs, but some used fixed CEPs. Different kinds of target installations were assigned different relative values by the various analysts, and different analysts used different rules to determine whether a MK4A or a MK5A RB would be assigned to strike a particular target. Different analysts used different metrics to assess the overall effectiveness of the various strikes. The usual practice was to change types of candidates being used in MK4A RBs while holding the MK5 warhead constant, then to change the types of candidates being used in MK5A RBs while holding MK4 warhead constant. This approach indicated the sensitivity of the effectiveness of the total SSBN/SLBM force against a total target base to the choice of warhead candidate.

(U) Submarine Operating Areas

(U) Another SPETWG force effectiveness model assumed that the ocean operating areas are constructed for a candidate option based on the range at maximum footprint of the shortest range missile in each ocean. In the Atlantic, the backline of the operating area is defined by the range to Moscow or is constrained by the SOA and South America. In the Pacific, the backline is defined by the range to the nearest SS-18 silo field for TRIDENT II (D5) SSBNs. This constraint also provides an adequate set of targets for TRIDENT I (C4) SSBNs. Table 9-4 shows the missile ranges and operating areas used for various configurations of the D5 missile carrying W88/MK5 warheads. Backlines for the MK4A and MK5A candidates are similarly developed using their missile ranges.

U) The analysis was conducted using a model that reflects the values of nuclear warhead yield and accuracy and estimates damage recognizing target hardness. The groups of targets were "attacked" in priority order from the most important to the least important. Weapons were selected from the appropriate legs of the TRIAD and were allocated to assure complete coverage of a group before proceeding to the next group. Although targets were assigned to different priority groups, all targets were given equal value. The allocation of weapon resources to priority groups was handled by heuristics meant to simulate STRATCOM implementation of national policy directives. Within a single priority group, optimum weapon assignments were achieved by using a modified Simplex Algorithm.

(U) This approach to estimating strategic damage effectiveness indicated that in some cases, where the candidate SLBM warheads were less effective, other legs of the TRIAD could recover some of the loss in effectiveness.

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9.4. (U) EFFECTIVENESS ASSESSMENTS AND RESULTS

9.4.1. (U) SUMMARY OF EFFECTIVENESS STUDIES

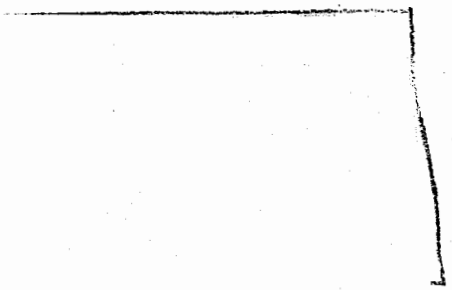
9.4.1.1. (U) MK4A

(U) Figure 9-26 shows the overall effectiveness scores for each MK4A candidate. These scores are based on an average of all the various SPETWG approaches, from combinations of MOEs to overall force effectiveness assessments. This result is a summary of all analysis approaches averaged together; for force level analysis alone, for MK4A.

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FIGURE 9-26a
(U) OVERALL MK4A EFFECTIVENESS RELATIVE TO W76



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9.4.1.1.1. (U) *Details of Effectiveness Analysis -- MK4A*

(U) Values comprising the overall SPETWG effectiveness scores are shown in figure 9-26b for the MK4A candidates. Each line represents a different figure of merit used in the overall average, from a basic SSPK MOE to force effectiveness assessments. The ROMA and WESVA categories represent effectiveness scores from the effectiveness sections of these spreadsheet models.

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FIGURE 9-26b
(U) OVERALL MK4A EFFECTIVENESS

9.4.1.2. (U) MK5A

(U) Figure 9-27 shows the overall effectiveness scores for each MK5A candidate. These are also based on an average of all the various SPETWG approaches, from combinations of MOEs to overall force effectiveness assessments. This result is a summary of all analysis approaches averaged together; for force level analysis alone, the trend for MK5A is similar between candidates.

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FIGURE 9-27a
(U) OVERALL MK5A EFFECTIVENESS RELATIVE TO W88

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9.4.1.2.1. (U) *Details of Effectiveness Analysis -- MK5A*

(U) Values comprising the overall SPETWG effectiveness scores are shown in figure 9-27b for the MK5A candidates. Each line represents a different figure of merit used in the overall average, from a basic SSPK MOE to force effectiveness assessments. The ROMA and WESVA categories represent effectiveness scores from the effectiveness sections of these spreadsheet models.

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FIGURE 9-27b
(U) OVERALL MK5A EFFECTIVENESS

9.4.2. (U) SPECIFIC EFFECTIVENESS RESULTS

9.4.2.1. (U) SSPK Effectiveness

(U) Because of the importance of SSPK in evaluating effectiveness, the following section will present an SSPK summary for the candidates against a variety of target hardnesses.

9.4.2.1.1. (U) *MK4A*

[redacted] Figure 9-28 compares the effectiveness of MK4A candidates on a C4 missile for targets up to 1000 psi and shows the hardness distribution of targets in the 1992 NTB (Russia Only).

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(U) EFFECTIVENESS OF MK4A CANDIDATES ON C4 VERSUS TARGET HARDNESS

FIGURE 9-28

FIGURE 9-29
(U) EFFECTIVENESS OF MK4A CANDIDATES
ON C4 VERSUS 27P0 TARGETS

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FIGURE 9-30
(U) EFFECTIVENESS OF MK4A CANDIDATES ON D5 VERSUS TARGET HARDNESS

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FIGURE 9-31
(U) EFFECTIVENESS OF MK4A CANDIDATES
ON D5 VERSUS 46L8 TARGETS

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9.4.2.1.2. (U) *MK5A*

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FIGURE 9-32
(U) EFFECTIVENESS OF MK5A CANDIDATES
ON D5 VERSUS TARGET HARDNESS

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FIGURE 9-33
(U) EFFECTIVENESS OF MK5A CANDIDATES ON D5 VERSUS 52L7 TARGETS

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FIGURE 9-34

(U) EFFECTIVENESS OF MK5A CANDIDATES ON D5 VERSUS 64L9 TARGETS

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9.4.2.2. (U) Force Effectiveness Analysis

9.4.2.2.1. (U) *Summary*

(U) Four force level effectiveness assessments were performed by the SPETWG. Choices of target bases, target worth weightings, missile launch points, and assessment metrics all varied from analyst to analyst. Even so, the normalized results showed consistent overall trends.

(U) Three of the studies used START II forces and target bases, one used START I forces and target base. Each target base was different. In each case there were more targets than weapons. All the studies except one used range variable CEPs from a set of assumed launch points; one used a constant CEP value. One of the studies used a weighting function to value some of the targets more than others; all others counted all targets equal.

9.4.2.2.2. (U) *MK4A*

(U) Figure 9-35 shows the normalized results of these four assessments for the MK4A candidates, along with a curve representing the average of the values. As seen, the four studies agree closely that all the MK4A candidates have essentially equivalent force effectiveness with respect to the MK4/W76.

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FIGURE 9-35
(U) MK4A NORMALIZED FORCE ASSESSMENT RESULTS

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FIGURE 9-36

(U) FORCE LEVEL EFFECTIVENESS VERSUS MK4A CANDIDATES

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9.4.2.2.3. (U) *MK5A*

(U) Figure 9-37 shows the normalized results of these four assessments for the MK5A candidates, along with a curve representing the average of these normalized values.

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FIGURE 9-37
(U) MK5A FORCE LEVEL ANALYSES SUMMARY

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Although the drop occurs at a rate that varies with the four studies, the general trend, indicated by the average, is consistent.

Figure 9-38 shows the effectiveness of MK5A candidates on a D5 missile for a 14 TRIDENT II (D5) SSBN force configuration.

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FIGURE 9-38
(U) FORCE LEVEL EFFECTIVENESS VERSUS MK5A FORCE SIZE

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9.4.2.2.4. (U) *MK5A Yield*

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Figure 9-39 shows an example of this tradeoff over the yield range of interest for this study. The changes in effectiveness result from an increase in the number of targets killed with higher yield versus a loss in effectiveness due to the increased weight necessary to obtain the higher yields and the resulting loss in missile range. While, increased yield gives a greater probability of damage (P_d) against a target, the increased weight and resulting decrease in range mean that fewer targets can be reached from the launch areas assumed. As a result, the number of targets killed can go down even as yield is increased. For each yield shown on the abscissa, the number of targets killed with a P_d greater than either 0.5, 0.7, or 0.9 is shown on the ordinate. The only targets considered for this assessment are ICBM silos under START I. Choosing a minimum P_d, an optimum yield can be found.

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Selecting a different minimum P_d or a different target base will alter the results. A harder target base will drive the optimum yield up. A larger target base with many softer targets will drive it down. A smaller acceptable P_d will also drive the optimum yield down. Note that the baseline W88 is optimum for its yield and weight regime, and is shown in Figure 9-39 on the far right.

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FIGURE 9-39
(U) YIELD FOR THE MK5A

9.5 (U) CONCLUSIONS

(U) The SPETWG assessments led to the following overall effectiveness conclusions.

9.5.1 (U) COMPARISONS OF MK4A CANDIDATES

The DOE weapons laboratories proposed eight candidates to replace the W76/MK4.

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The MK4 mission can also be accomplished with candidate LA5-2 on the D5 missile with approximately the same effectiveness as the baseline.

(U) The impact of missile range on the comparison of MK4 candidates should also be noted. The differences in weight of the MK4A candidates reduce full load (eight RBs) range of the C4 missile to a point where operational viability becomes a serious concern. This range is critical for the C4 missile whose deployment is on the TRIDENT submarine in the Pacific Ocean. The eight body range criterion, however, is not an effective discriminator among the candidates. Range of the C4 missile with only four RBs, a potential loading under START II rules, is large and the additional weight of the candidates is not an important discriminating factor. Range of the D5 missile, even with eight of the MK4A candidates, is not a significant issue for operations in either the Atlantic or the Pacific Ocean operating areas.

9.5.2. (U) COMPARISONS OF MK5A CANDIDATES

[redacted] Twenty-two candidates were proposed by the DOE weapons laboratories to replace the W88/MK5. While the W88/MK5 is more effective than any of the

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10. SURETY

10. (U) SURETY

10.1 (U) SAFETY ATTRIBUTE IMPLEMENTATION

10.1.1 (U) INTRODUCTION

(U) The scope of this study was to review the safety attributes of the Phase 2 candidates and to identify the issues and concerns associated with implementing modern safety features. The scope did not include determining the relative need for these features in the TRIDENT weapon system.

(U) Many of the proposed warhead candidates contain a number of safety features which can enhance nuclear safety and reduce the probability of Pu dispersal with minimal impact to the weapon system. These features are grouped into two basic categories: safety systems which are common to a number of candidates; and second, unique safety systems which are specific to a single candidate or small group of candidates. The features which are common to a number of candidates include; IHE, FRPs, robust exclusion barriers, and advanced detonator safing.

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(U) In Section 10.1.2, details of a number of safety features are discussed. Subsequently, candidate-specific ENDS themes, and an assessment of INRAD exposure levels are presented in Sections 10.1.3 and 10.1.3. In Section 10.1.5, Tables 10.1-2 to 10.1-5 detail the safety implementation scheme for all candidates, indicating the safety features incorporated and those which require excursions from the defined ground rules (e.g., impacts to missile system). The conclusions from this Safety Technical Working Group safety review are contained in Section 10.1.6.

(U) Recently, the possibility of plutonium scatter from nuclear weapons exposed to abnormal environments has received increasing attention. Plutonium dispersal safety features have been emphasized for all Phase 2 candidates.

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10.1.2 (U) SAFETY FEATURE DISCUSSION

10.1.2.1 (U) Insensitive High Explosive (IHE)

(U) The IHE formulations used by LLNL and LANL for nuclear weapon main charge high explosives are based on plastic bonded triaminotrinitrobenzene (TATB). LX-17 (92.5/7.5 wt% TATB/Kel-F 800) is used in LLNL designed weapons, while PBX 9502 (95/5 wt% TATB/Kel-F 800) is used in LANL weapons. The overall characteristics of these formulations are almost identical in safety and performance properties. The LX-17 has slightly higher physical strength properties when compared to PBX 9502.

(U) The IHEs have been demonstrated to be highly resistant to accidental initiation of a high explosive violent reaction or detonation that would result in Pu scatter in abnormal environments. Weapon systems containing IHE have been subjected to high velocity impact, fuel fires, propellant fires, bullet impacts, and sympathetic detonations from near-by warheads. Los Alamos and Sandia conducted rocket sled tests in which weapons containing PBX 9502 were impacted into rigid concrete targets at velocities ranging from 500 ft/s to 2000 ft/s. In these tests the PBX 9502 did not respond in a violent reaction or detonation. Both LANL and LLNL have subjected weapons containing IHE to fuel fires (~1 hour duration) and propellant fires (<20 minutes). In these tests the IHEs did not react violently or detonate as a result of the abnormal thermal environments. Bullet tests using 0.223 cal., 0.30 cal., 0.50 cal., 30-mm uranium and 30-mm tungsten projectiles have not resulted in violent reactions of the IHEs in full scale weapon and weapon cross-section targets. Nearby warhead sympathetic detonation tests were conducted by LANL using B61 bombs with stockpile separation distances for testing. In these configurations, the "donor" warhead, when initiated, did not produce a reaction in the near-by "acceptor" warhead. Pieces of PBX 9502 and the mock pit were recovered after the tests. Full scale tests, along with many component safety tests, conducted by LANL and LLNL have demonstrated the safety properties of IHE in these abnormal environments.

[redacted] The Warhead Sensitivity Study (Reference 8) found that IHE would detonate in response to a hypothetical third stage rocket motor detonation.

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This evaluation has been partially completed, and no problems have yet been identified. See Section 10.1.2.1.3.

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10.1.2.1.1 (U) *LANL One Point Safety*

(U) All LANL MK4A and MK5A candidates are designed to be one point safe. Two-dimensional and three-dimensional analyses, along with some UGTs, have been used to evaluate the safety of the candidates.

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10.1.2.1.2 (U) *LLNL One Point Safety*

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10.1.2.1.3 (U) *LANL Beyond One-Point Nuclear Safety Analysis*

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10.1.2.2 (U) Fire Resistant Pit Design

(U) Plutonium containment requirements for the Phase 2 study have not been completely specified. STS requirements have been revised to specify a fuel fire of 1100°C for one hour at a Strategic Weapons Facility and potentially a much greater time when not at a Strategic Weapons Facility.

10.1.2.2.1 (U) *LLNL FRP Design Concepts*

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(U) The Design Laboratories have been developing fire resistant pit designs for the reduction of plutonium scatter in fire environments for well over a decade. The fire resistant pit designs have been fielded in the W84, B83 and W87, and the concepts for fire resistance have been continually improved leading to the current design standard developed into Phase 4 for the W89. The MK4A and MK5A candidates take advantage of these developments.

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(U) Helium builds up in the plutonium from radioactive decay. In elevated temperature-aging studies on plutonium from old W68 pits, no change in density or other undesirable characteristics were detected. Upon melting in containment tests, a release of the helium has been noted, but there has been no detectable adverse effect on the containment capability. Helium build-up does not appear to be an issue.

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10.1.2.2.2 (U) *LANL FRP Design Concepts*

(U) Because the duration of fires while in DOE custody is yet to be determined, LANL has adopted the requirements of 1100°C for two hours as its requirement for fire resistance. Fire resistance reduces the chance and/or magnitude of Pu dispersal in accidental fires.

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10.1.2.3 (U) Detonator Safing

10.1.2.3.1 (U) *LLNL/Sandia Detonator Safing Stronglink (DSSL)*

(U) The Detonator Safing Stronglink employed by LLNL/Sandia is a nuclear safety subsystem which embeds one of the two safety-critical stronglinks deeply within the NEP. It is designed to provide a safe and predictable response in all credible environments until receipt of the correct unique prearm signal. The DSSL reduces the risk of inadvertent nuclear detonation over conventional detonators with fireset-based stronglinks by interrupting the detonation train within the NEP. This is particularly valuable in the case of severe combined accident environments in which the fireset may become separated from the NEP resulting in exposed detonator cables.

(U) The DSSL safety subsystem was developed for the W89 (SRAM-II and SRAM A). It is a mature technology (low technical risk) which has been developed well into Phase 4. It was derived from the MSAD (Mechanical Safe and Arm Detonator) which is in the stockpile in the MK21/W87 on the Peacekeeper ICBM and on the W84 ground launched cruise missile (GLCM) now in inactive reserve (IR).

(U) The DSSL consists of two basic subsystems: the actuator and warhead detonators (which each contain a unique-signal discriminator/safing mechanism). The actuator is mounted external to the NEP and receives a unique electrical signal from either the missile or a unique signal generator. The actuator uses the unique signal to enable the discriminator/safing mechanism associated with each detonator inside the NEP.

(U) The detonators each contain an electrical bridge which can be exploded by high current. The exploding bridge drives a flyer plate, which, in normal operation, impacts and detonates a small PETN explosive pellet. The PETN detonation, in-turn, drives an aluminum flyer which initiates a large booster pellet leading to the detonation of the main explosive charge. In typical (non-DSSL) flyer plate detonator designs, these components of the detonation chain are in the aligned position. For these aligned detonators, initiation of the bridge will light the main charge. Similarly, abnormal environment initiation of the PETN pellet will also initiate the main charge.

(U) In DSSL the PETN pellet is mounted in a cogged wheel, known as the discriminator wheel. Prior to prearming the DSSL, the discriminator wheel is positioned such that the PETN pellet is not aligned with either the detonator bridge or the detonator output barrel. In this position, firing the detonator bridge cannot initiate the PETN, nor could initiation of the PETN initiate the booster. Thus, the PETN pellet is isolated from the electrical source which can initiate it (the exploding bridge and flyer) and the main explosive charge is isolated from the PETN. Even if the PETN were initiated directly by some shock wave from other than the exploding bridge, it would not be able to initiate the IHE from its safed position. The detonator is inoperable until it receives the correct unique signal.

(U) To prearm the DSSL, the discriminator wheel is rotated by a series of pushes and pulls which are sent down a mechanical cable from the DSSL Actuator. If an incorrect sequence of signals is applied, the discriminator wheel will be driven to an irreversible, mechanically-locked, and safe state. The explosive pellet would remain out of line and incapable of detonating the IHE main charge. The DSSL mechanism and unique signal have been designed such that the device is highly unlikely to be enabled by energy sources found in normal or abnormal environments.

(U) The PETN pellet acts as a thermal weaklink. The pellet completely decomposes (does not detonate or ignite) at around 450°F, rendering the detonator predictably and irreversibly inoperable well before the discriminator mechanism and the stainless steel DSSL barrier lose their integrity. The DSSL does not have a defined mechanical weaklink. Therefore, Sandia cannot categorically state that it is impossible for mechanical environments to drive the code wheels into their prearmed positions. However, as the cables are not directly connected to the discriminator wheel, it would be extremely unlikely for this to occur. An abnormal mechanical environment is much more likely to detach or damage the cables than to apply the required unique series of pushes and pulls. This is particularly true relative to detonators, which do not require any unique signals for prearming.

(U) The DSSL is much less vulnerable to mechanical abnormal environments than many other safety subsystems. A single g-time pulse is insufficient to prearm the device regardless of duration or amplitude. Performance can be contrasted to an ESD, which can be set by a single linear g-time pulse.

[redacted]

(U) The DSSL is also insensitive to electrical environments including direct lightning strikes. Each DSSL detonator has two cable assemblies: the detonators use flat detonator cables to their bridges; and the DSSL mechanisms have mechanical drive cables. During development of the W89, special attention was given to preventing detonation through the propagation of lightning along these lines resulting in an improved and tested design.

10.1.2.3.2 (U) *LLNL/Sandia Paste Extrudable Explosive (PEX) Booster*

(U) The Paste Extrudable Explosive (PEX) booster found in some LLNL/Sandia designs is a recently-developed nuclear safety subsystem. Its function is to provide a second stronglink buried within the NEP - thus complementing the DSSL system described earlier. It eliminates the potential for even an armed DSSL to initiate the main charge by removing a essential component of the HE initiation chain.

(U) The output from a warhead detonator (including a prearmed DSSL or the detonators in the W76 or W88) is not sufficient to directly initiate the IHE main charge. Initiation of IHE by firing one of these detonators requires that the detonator first initiate a small explosive charge (booster) which is more easily initiated than the IHE, and which has higher output than the detonator. The output from the booster is sufficient to initiate the IHE. In the PEX booster design, the booster explosive is a paste, which is stored outside the NEP and injected into the NEP only after prearming (receipt of a unique signal). The paste explosive is a thick, viscous gel of HMX explosive, thickener, and solvents.

(U) The PEX for each booster is stored in its own separate reservoir which is connected by tubing to a booster cavity in the NEP. The plumbing for each booster is entirely separate from any other booster, so that an initiation of one booster, anywhere along the transfer tube, at the cavity, at the reservoir, etc., cannot propagate through the plumbing to another booster. This precludes the possibility of multi-point initiation of the IHE caused by single-point initiation of the PEX. The tubing between the reservoirs and the NEP is interrupted by a unique signal-operated stronglink valve. The PEX cannot be transferred into the NEP unless the stronglink valve receives its unique signal to operate.

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10.1.2.4 (U) Exclusion Regions and Barriers

10.1.2.4.1 (U) *LLNL Robust Exclusion Barrier*

(U) The purpose of the robust exclusion barrier is to provide a stronger exclusion barrier between the stronglinks in the AF&F and the NEP. The barrier will fully contain the detonator leads and will provide improved thermal protection up to and including fuel fires.

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10.1.2.4.2 (U) *LLNL Tough Case*

(U) Due to the characteristics of IHE, its very slow burn rate, and its insulating thermal properties, it provides a very good thermal blanket which may be capable of protecting the pit in abnormal fire environments. The difficulty, however, is that as the IHE burns, it generates massive amounts of gas which can "overpressure" the NEP leading to disassembly of the mechanical joints. The tough case design addresses a number of issues associated with maintaining NEP case integrity during a fire environment.

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10.1.2.4.4 (U) *LANL Exclusion Barriers*

(U) To improve nuclear detonation safety in abnormal environments, detonator cables require improved shielding from possible abnormal electrical environments. The exclusion barriers should have the capability to withstand temperatures exceeding 1000°C, should provide for no line-of-sight to detonator cables, should maintain good electrical continuity between the AF&F and the warhead case, and should provide a strong mechanical mounting scheme between the AF&F and the NEP.

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(U) Los Alamos made a serious effort to design an exclusion region that would satisfy all requirements for ENDS. However, in the judgment of LANL and Sandia, only incremental improvements can be made toward ENDS, unless considerable modifications to the AF&F, RB, and warhead are made. See Section 5.1.4.3.3.

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10.1.3 (U) ENHANCED NUCLEAR DETONATION SAFETY (ENDS)

10.1.3.1 (U) Electrical Nuclear Safety Theme

10.1.3.1.1 (U) *LANL/Sandia MK5A Electrical Nuclear Safety Theme*

(U) The electrical nuclear safety theme for almost all Phase 2 MK5A replacement warheads is similar to that of the W88/MK5 with the additional positive isolation feature of detonator safing to preclude initiation of detonators until specific functions occur enabling them. A summary of the W88/MK5 electrical nuclear safety theme is provided and is applicable to essentially all MK5A candidates.

(U) The electrical nuclear safety theme for the W88/MK5 is based on the principles of isolation, incompatibility, and inoperability and has two major parts, (1) to preclude unintended charging of the fire set Capacitor Discharge Unit (CDU) capacitors, and (2) to preclude shorts to the weapon detonator cables that could bypass the CDU.

(U) The following design objectives were formulated for the W88/MK5 to achieve the nuclear safety requirements specified in the MCs.

1. The system shall remain safe until an unambiguous indication of intended use is received.
2. The warhead shall respond to abnormal environments in a predictably safe manner.
3. The design shall meet nuclear safety requirements without the need for a detailed description of the abnormal environments that might be encountered in credible accident scenarios.

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(U) The design effort to implement the electrical nuclear safety theme resulted in the following system features:

1. Three independent safety subsystems, Intent, Trajectory, and Arming.
2. Exclusion region barriers to isolate the safety-critical components from available electrical energy sources.
3. Stronglink devices requiring unique enabling signals to control the transfer of electrical energy into the exclusion region.
4. Dual exclusion regions, each containing a CDU for detonator firing, without a common interconnection.
5. Collocation of stronglink and weaklink devices to ensure that each receives similar environment exposure.
6. Weaklink (HE) that becomes irreversibly inoperable in abnormal thermal environments before stronglink or barrier failures occur.
7. Widely separated (foam isolator protected) and shielded detonator cables.

(U) The Intent and Trajectory subsystems each provide independent 24-event unique signals for driving the dual stronglink assembly to the enabled position. Intent requires human action and implies a person's intention to launch the missile. Trajectory signals are derived from information developed by the missile in flight. The Arming subsystem includes the issuance of two independent electrical signals and the resultant charging of the CDU. The two required electrical arming signals are isolated from the receptor circuits by a fuse switch and by the launch accelerometer inside the AF&F. Critical circuitry of the fire set is contained within two independent exclusion regions to exclude all energy sources until intended mode operation is initiated.

(U) The electrical nuclear safety theme features and characteristics for the Phase 2 Study replacement warhead candidates are similar to the features designed into the W88/MK5 system. A third major part is added to those candidates that are compatible with detonator safing technology "to preclude initiation of system detonators until specific action is taken to enable those detonators". The Intent and Trajectory subsystems provide the unique signals required to enable the detonator enable/safe system. Detonator safing is described in the Safety Feature Discussion

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section of this report. In addition, if the Phase 2 Study constraints are changed to allow modification of the MK5 AF&F, a new doped-mylar "weak-link" capacitor will be included in the fire set output.

(U) The thermal weaklink in the W88/MK5 is the conventional HE in the warhead. Tests and analyses show this to be an acceptable weaklink. A study was undertaken in FY93 to identify potential thermal failure modes within the MK5 AF&F. Testing confirmed the existence of failure modes in the Dual Stronglink Assembly (DSA) inside the AF&F prior to loss of electrical isolation. These failure modes enhance the likelihood of a safe response in thermal environments and complement the HE weaklink degraded by the change to IHE and the increased high explosive spacing in the Phase 2 candidates.

(U) The study has identified irreversible, independent, yet predictable, failure modes in the MC3831 DSA resulting from exposure to abnormal thermal environments. The abnormal temperature requirement for the DSA is 650°C due to the nuclear critical safety springs in the Module D becoming indeterminate at that temperature. . Study results identified two failure modes, one involving the Duplex Bearings used in the Module C Intent Stronglink, and the second involving transformers. Module C permanent bearing seizure occurs at a temperature between 350°C and 400°C. Permanent transformer failure, precluding transfer of energy into the exclusion regions, occurs between 280°C and 435°C. Failure mode temperatures are reached in both the bearings and the transformers, under worst-case conditions (smart fire directed at the flat side of the fireset housing closest to the springs), before the spring temperature reaches 650°C.

10.1.3.1.2 (U) *LANL/Sandia MK4A Electrical Nuclear Safety Theme*

(U) The electrical nuclear safety theme for all Phase 2 MK4 replacement warheads is similar to that of the W76/MK4 with the additional positive isolation feature of detonator safing to preclude initiation of detonators until specific functions occur enabling them. A summary of the W76/MK4 electrical nuclear safety theme is provided and is applicable to all MK4A candidates.

(U) The electrical nuclear safety theme for the W76/MK4 is based upon isolation of electrical signals, diversion of electrical energy, and a predictable response relationship between components in credible abnormal environments.

(U) Isolation consists of positive measures (accelerometer and decelerometer) to preclude application of medium-voltage thermal battery power to the fire set except under intended use conditions.

(U) Energy diversion complements isolation. It consists of positive measures (Lightning Arrestor Connector (LAC)) to divert any electrical energy sufficient to cause weapon detonation.

(U) The predictable response relationship consists of positive measures to:

1. Preclude warhead operation except under normal flight conditions.
2. Assure absence of any credible warhead detonator electrical initiation source other than the armed firing set.
3. Preclude operation of critical safety components by available energy sources other than the intended source.
4. Assure that the reaction of critical safety components to environmental stresses is such as to result in a fail-safe response.

(U) A stronglink-weaklink approach is incorporated in the implementation of the safety theme. The accelerometer and decelerometer (stronglinks) provide electrical isolation by sequentially controlling access to the arming and firing circuits. The fireset itself is the weaklink and is designed to become irreversibly inoperable at environmental stress levels below those which could cause stronglink failure. Protection from a direct lightning strike is provided by the combination of the LAC, the incorporation of two stronglink switches, and the exclusion region barrier surrounding the safety-critical components.

(U) The electrical nuclear safety theme for the Phase 2 Study replacement warhead candidate LA4-1 is similar to the W76/MK4 weapon system theme. An additional positive isolation feature, detonator safing, is added in the LA4-2 candidate which modifies the safety theme "to preclude initiation of system detonators until specific functions occur enabling the detonators."

10.1.3.1.3 (U) *LLNL/Sandia MK5A Electrical Nuclear Safety Theme*

All of the LLNL/Sandia MK5A candidates are based on using the existing W88/MK5 MC3810 AF&F and are compatible with DSSL. The larger size and weight capacity of the MK5A (as compared to the MK4A) allow freedom to explore significantly different safety themes.

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[LLNL MK5A candidates can be grouped into five categories. The ENDS themes for each category are discussed below.

(U) 1) LL5-1, -2, -3. These candidates all incorporate a DSSL and a robust exclusion barrier between the AF&F and the NEP. The robust exclusion barrier between the AF&F and the NEP provides enhanced safety in abnormal mechanical environments. It may reduce the likelihood that the AF&F will become detached from the warhead, thus exposing the detonator cables and bypassing the stronglinks within the AF&F. However, in these designs, the DSSL maintains safety in this situation as detailed in the DSSL description.

(U) 2) LL5-4a, -4c. These candidates have all of the safety features of the LL5-1, -2, -3 designs. In addition, the nuclear package is surrounded by an accident-resistant case. The accident-resistant case enhances safety in abnormal thermal environments.

(U) 3) LL5-4b. This candidate has a nuclear package that is similar to the LL5-4a, -4c designs. The primary difference is that LL5-4b contains a Category F Permissive Action Link (CAT-F PAL). Because of volume constraints, the accident-resistant case is not used in this design. The CAT-F PAL requires relocation of the firing set, and also requires two stronglinks between the relocated firing set and the primary detonators. The stronglinks in the existing MC3810 AF&F do not play an IND safety role in this design. In their place the DSSL and PEX booster are substituted.

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10.1.3.1.4 (U) *LLNL/Sandia MK4A Electrical Nuclear Safety Theme*

(U) From an ENDS perspective, all of the LL4-Xa candidates are the same. Therefore, they all use the same ENDS themes. The LLNL/Sandia candidates proposed for the MK4A are designed to enhance two aspects of nuclear safety: reducing the likelihood of structural breakup and providing detonator safing.

(U) To provide positive protection, even if the NEP becomes exposed in an accident, LLNL/Sandia candidates include a DSSL downstream of the detonator cables, within the NEP itself. As long as the DSSL has not received the correct unique signal (i.e., been prearmed), firing of the detonator bridges cannot initiate the main charge explosive.

(U) This aspect of nuclear safety can be further improved in the LL4-Xb candidates by incorporating PEX Booster. Including a PEX booster system requires a new AF&F.

(U) The DSSL in LLNL/Sandia candidates provides improved safety in abnormal environments. Prearming stronglinks by unique signals which require many separate events provides greater assurance that the stronglinks will not be prearmed inadvertently. A signal generated by many events is much less likely to be inadvertently generated than one which requires only one event.

(U) The MK4A candidates could be fielded without DSSL or PEX booster.

(U) Unique Signal Generation: On the D5 missile, the unique signal to prearm DSSL would come from the Intent word which is sent in flight from the missile to the RBs. The use of a human intent signal to prearm DSSL provides the optimal safety for this design. However, the C4 missile system does not have any unique signal capability, and, therefore, is currently incompatible with this implementation. Therefore, for LLNL MK4A warheads on C4 missiles, an ESSG will be required to construct a unique signal by sensing a series of combinations of go/no-go environmental inputs, including acceleration and electrical signals from the missile. This ESSG would be designed to prearm the DSSL if the ESSG sensed events consistent with an SLBM flight, and will lock the DSSL in a safe position if it senses events which are not consistent with SLBM flight (i.e., abnormal environment). These SLBM events would be selected to discriminate between an SLBM flight and any abnormal environment, such as an aircraft crash.

(U) Modifying the MK5 to MK4 Adapter Cable on the D5 missile, which is outside the Phase 2 study groundrules, would allow the MK5 unique signal messages to be transmitted to the MK4A when mated to the D5 missile. This would eliminate the need for an Environmental Sensing Signal Generator in that application.

10.1.4 (U) INRAD EXPOSURE LEVELS

(U) Predictions for INRAD operational exposures for all Phase 2 warhead candidates have been made. The predictions are based upon a methodology that requires knowledge of neutron and gamma INRAD dose rates for each candidate, as well as operational exposure data that can be unambiguously linked to specific existing

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FIGURE 10.1-1
(U) SUMMARY OF INRAD EXPOSURE PREDICTIONS FOR LANL PHASE 2 WARHEAD CANDIDATES
(PREDICTIONS BASED ON MK4/W76 EXPOSURE DATA)

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FIGURE 10.1-2
(U) SUMMARY OF INRAD EXPOSURE PREDICTIONS FOR LLNL PHASE 2 WARHEAD CANDIDATES
(PREDICTIONS BASED ON MK4/W76 EXPOSURE DATA)

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TABLE 10.1-2

(U) LANL/SANDIA MK5A CANDIDATE SAFETY IMPLEMENTATION

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TABLE 10.1-2 (Continued)

(U) LANL/SANDIA MK5A CANDIDATE SAFETY IMPLEMENTATION

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[redacted]

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TABLE 10.1-4

(U) LLNL/SANDIA MK5A CANDIDATE SAFETY IMPLEMENTATION

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TABLE 10.1-4 (Continued)
(U) LLNL/SANDIA MK5A CANDIDATE SAFETY IMPLEMENTATION

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TABLE 10.1-5
(U) LLNL/SANDIA MK4A CANDIDATE SAFETY IMPLEMENTATION

10.1.6 (U) CONCLUSIONS

(U) The STWG developed the following conclusions from its Phase 2 study effort:

1. (U) The W76/MK4 and the W88/MK5 meet the intent of all safety requirements as specified in the MCs and STSs. The STWG has not identified any safety concerns with the as-designed weapon systems. New advanced technology developments could be incorporated into system designs that offer safety enhancements to the existing MK4 and MK5.

2. (U) The proposed candidates take advantage of new technology design features/enhancements. Safety systems that can be implemented on Phase 2 candidates which are common to a number of candidate warheads are IHE, fire resistant pits, robust exclusion barriers, and advanced detonator safing (DSSL, SALAD).

3. (U) The enhanced safety concepts and features discussed herein can be incorporated into the Phase 2 candidates without violating groundrules with the exception of the LA4-1 and 2, LA5-5, LL5-5 and LL5-6 designs, and the candidates that incorporate CAT F use control features in their designs.

4. (U) The electrical nuclear safety theme to prevent inadvertent nuclear detonation for MK5A candidates is similar to that of the W88/MK5, with the additional positive isolation feature of detonator safing.

5. (U) The electrical nuclear safety theme to prevent inadvertent nuclear detonation for MK4A candidates is similar to that of the W76/MK4 with the additional positive isolation feature of detonator safing.

6. (U) No attempt was made to quantify the merits of any proposed safety features. An extensive trade-off study would be required to evaluate safety features and their impact on system performance and reliability. Further detailed studies would also be required to quantify safety enhancements and improvements in system safety.

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8. (U) The STS fire and nearby explosion environments have not been completely defined. Additional details on the DOE SST operations and the nearby explosion environments are needed for continued assessments.

10.2 (U) USE CONTROL

(U) This section addressed the implications of recommendations made by the Fail-Safe and Risk Reduction Committee (FARR) affecting SLBM reentry systems. The FARR working group reviewed the 58+ FARR Committee recommendations for their applicability to the TRIDENT Phase 2 Study.

(U) The following two FARR recommendations, dealing with coded control and use denial, were found to be applicable to the TRIDENT Phase 2 Study:

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(U) The issues of coded control and use denial can be addressed at the reentry system level by employing combinations of four warhead use control implementations:

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(U) MK5A warhead candidates have been proposed that can incorporate each type of use control device (CAT-D, E, and F PALs). MK4A warhead candidates have been proposed that can incorporate only CAT-D and CAT-E PALs.

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Table 10.2-1 summarizes which use control features can be implemented in the various warhead candidates.

(U) The Phase 2 Study was limited to identifying alternate warhead candidates for the W76/MK4 and W88/MK5. Consequently, the study group could only address implications of coded control and use denial options in the warhead and Reentry systems.

(U) Incorporation of various combinations of coded control and use-denial devices can satisfy the FARR recommendations. However, an optimal solution that incorporates coded-control and use-denial devices in combination must consider the entire weapon systems. Determining the impacts of design changes in other

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subsystems of the weapon systems, such as Fire Control, Launcher, etc., were beyond the scope of this study.

(U) The impacts of CAT-D, E, and F PAL and CD warhead implementations on the weapon systems likewise were not evaluated. Areas that would be affected include the following:

- Missile/Reentry body interfaces
- Fire Control
- Launcher
- Logistics/Operations
- Safety

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11. ENVIRONMENTAL EFFECTS ASSESSMENT

11. (U) ENVIRONMENTAL EFFECTS ASSESSMENT

(U) There will be no adverse environmental effects from the development, production, testing or stockpiling of the MK4A and MK5A reentry body assemblies and their warheads that are outside of Department of Energy and Department of Defense guidelines for nuclear weapons. Information concerning the environmental impact assessment of the TRIDENT strategic weapon system may be obtained from the Director, Strategic Systems Programs.

12. CONCLUSIONS

12. (U) CONCLUSIONS

12.1 (U) BACKGROUND

(U) The guidelines established for this Phase 2 Study included tasking to "identify and quantify a broad range of alternate reentry systems for use on the TRIDENT weapon systems that emphasize longevity, increased safety margin, system reliability, and future requirements."

(U) Although the present systems are, as President Clinton, the Navy and DOE have said, safe and reliable, all of the replacement warhead candidates considered in the Phase 2 study offer surety enhancements over the currently deployed systems. Most candidates incorporate IHE, improved ENDS, FRP, and use control features. The Phase 2 Study Group evaluated these surety enhancements, and associated performance penalties and system impacts.

(U) The viability of some of the candidates depends upon the DOE's ability to produce new plutonium pits and whether the DOE weapons laboratories are permitted to conduct UGTs.

12.2 (U) EVALUATION APPROACH

(U) To examine the tradeoffs between attributes of candidates, two different evaluation approaches were developed in the System Performance and Effectiveness Technical Working Group (SPETWG). One approach is Weapon Safety Value Assessment (WESVA) (Reference 10) and the other is Relative Overall Merit Assessment (ROMA) (Reference 11).

(U) Both evaluation approaches make use of computer spreadsheets to combine figures of merit (FOMs) for each of the candidate warheads. These FOMs include the following: surety, effectiveness, vulnerability, production/logistics, engineering evaluation, and physics evaluation. Input is taken from the Phase 2 technical working groups.

(U) WESVA uses tradeoffs that measure how much the decision maker is willing to give up of one FOM to gain on another. ROMA assigns weighting coefficients to each of the FOMs that correspond to their assessed importance in overall value. The SPETWG members were polled for their preferences to establish the weighting and tradeoff measures. The spreadsheet format lends itself to interactive use, allowing the decision maker to easily test the sensitivity of results to input assumptions.

(U) The overall value of each candidate was estimated, along with its ranking relative to the W76 or W88. In all cases, no replacement candidates, MK4A or MK5A, were ranked higher than existing systems. The results presented in Section 12.3 are candidate groups which were differentiated from other candidates given the input assumptions. The candidate groups were found to be insensitive to a wide range of variations.

12.3 (U) FINDINGS

(U) The findings are presented for three potential situations which represent fundamentally different political realities and real world constraints.

12.3.1 (U) WITH UGT AND NEW PLUTONIUM PITS

(U) In this situation, the current UGT moratorium is lifted, thereby allowing development testing to demonstrate reliability and performance of replacement candidates that use new plutonium primary pits. This situation further assumes that the DOE weapons complex can manufacture new primary pits.

(U) Both the WESVA and ROMA assessment models indicate that the best alternatives for further consideration are **(the order is not significant)**:

MK4A on C4/D5:	LL4-3
	LA4-1
MK5A on D5:	LL5-2
	LA5-1

12.3.2 (U) WITH UGT AND REUSED PLUTONIUM PITS

(U) In this situation, the current UGT moratorium is lifted, but the DOE weapons complex precludes manufacture of new plutonium pits. Development testing is permitted to demonstrate reliability and performance of replacement candidates using existing primary pits.

(U) Both the WESVA and ROMA assessment models indicate that the best alternatives for further consideration are **(the order is not significant)**:

MK4A on C4/D5:	LL4-1
	LA4-2
MK5A on D5:	LL5-1 (H, M, or L)
	LL5-3a
	LL5-3b
	LA5-4 (H, M, or L)
	LA5-6

12.3.3 (U) WITHOUT UGT

(U) In this situation, the DOE nuclear design laboratories are precluded from conducting UGTs to develop replacement candidates. Historically, nuclear testing has been a necessary part of warhead development. Reducing the need for development nuclear testing is a significant challenge to a design philosophy that has relied on nuclear testing to demonstrate reliability and performance of complex systems that cannot be simulated any other way.

12.3.3.1 (U) MK4A Without UGT

(U) This study has not identified any MK4A candidates for further consideration without UGTs.

12.3.3.2 (U) MK5A Without UGT

(U) The Los Alamos and Livermore nuclear design laboratories have not reached agreement on how MK5A development and certification would be done without UGT.

(U) Pending the results from the joint laboratory peer review process and future inter-laboratory reviews during a Phase 2A or Phase 3, two positions, one each from Livermore and Los Alamos, are presented for the preferred candidates.

12.3.3.2.1 (U) *LLNL Position Without UGT*

(U) Many, but not all, of the development issues for several MK5A warhead candidates can be addressed with existing data from past nuclear tests. The following candidates have such a nuclear test background and merit further consideration as to whether or not they could be developed without additional nuclear testing. See Sections 5.2.2.1.2 and 5.2.2.2.2.

MK5A on D5	LL5-1
	LL5-2
	LA5-1

12.3.3.2.2 (U) *LANL Position Without UGT*

(U) It is the technical position of Los Alamos that any primary considered as a candidate for this Phase 2 should have or have had two successful nuclear tests in its final design configuration. Without this minimum number of tests, the confidence level of any laboratory certification would be significantly less than that of the system it will be replacing. Thus, the leading candidates that meet minimum yield and other military characteristics do not have sufficient test basis to allow certification without a serious degradation of the accompanying confidence level; the confidence level would be unknown. It is also the Los Alamos position that relaxation of MCs would still require at least one more test for certification of candidates LL5-1, LL5-2, and LA5-1. See Section 5.1.2.2.

MK5A on D5:	No candidates meet the requirements.

APP. A PHASE 2 REQUEST LETTERS

APPENDIX A

PHASE 2 REQUEST LETTERS (U)

(All Portions of This Appendix are UNCLASSIFIED)

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, DC 20350-2000

IN REPLY REFER TO

653C/2U639009
10 Apr 92

SECOND ENDORSEMENT on DIRSSP memo 4900 Ser SP272 Ser U032692113 of 26 Mar 92

From: Chief of Naval Operations (OP-65)
To: Chairman, Nuclear Weapons Council Standing Committee

Subj: SUBMARINE LAUNCHED BALLISTIC MISSILE (SLBM) REENTRY SYSTEM PHASE II STUDY

1. Forwarded, concurring with the recommendation to initiate a DOD/DOE Phase II study to identify and quantify technical alternatives to the MK4/W76 and MK5/W88.

R. L. TINDAL

Copy to:
OP-091B
DIRSSP

DEPARTMENT OF THE NAVY
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
WASHINGTON, DC 20350-2000

IN REPLY REFER TO
3960
Ser 21/2U584166
3 Apr 92

FIRST ENDORSEMENT on DIRSSP memo 4900 Ser SP272 Ser U032692113 of 26 Mar 92

From: Chief of Naval Operations (OP-21)
To: Chairman, Nuclear Weapons Council Standing Committee
Via: Chief of Naval Operations (OP-65)

Subj: SUBMARINE LAUNCHED BALLISTIC MISSILE (SLBM) REENTRY SYSTEM PHASE II STUDY

1. Forwarded, concurrring with the recommendation to initiate a DOD/DOE Phase II study to identify and quantify technical alternatives to the MK4/W76 and MK5/W88.

R. A. RIDDELL
By direction

Copy to:
DIRSSP

SLBM Reentry System Alternatives

Objective:

Identify and quantify alternate reentry systems for use on the Trident II strategic weapons systems. Alternatives should consider maximum use of existing DOD hardware in order to minimize system cost. The alternatives should be evaluated with regard to the following attributes:

- SLBM weapon system safety
- Desensitization to aging effects
- Minimum need for refit
- Reliability
- Cost (initial and life cycle)
- Compatibility with existing DOD hardware

Maximum yields commensurate with the above attributes should be identified. Both existing physics packages and those reusing existing plutonium primaries should be emphasized to minimize the impact on limited DOE production capacity.

If the DOE agrees to participate in this study, the Study Group will convene at the earliest date convenient to all study participants. Within 90 days of the initiation of Phase 2, the Study Group will present its goals, strategy, and milestones for conducting the study to the Nuclear Weapons Council Standing Committee (NWCSC). The NWCSC will review the progress and status of the study as necessary but at least annually.

Sincerely,

Bob Barker

Robert B. Barker

Enclosure

cc:
CNO (OP-65)
CNO (OP-91B)
CNO (OP-02)
DIRSSP

APP. B MILITARY CHARACTERISTICS

APPENDIX B

MILITARY CHARACTERISTICS FOR THE WARHEAD FOR THE TRIDENT II (D-5) MK5A AND MK4A REENTRY BODY (U)

(This page is UNCLASSIFIED)

MILITARY CHARACTERISTICS FOR THE WARHEAD FOR THE TRIDENT II (D-5) MK5A REENTRY BODY (U)

1. (U) GENERAL

(U) 1.1 Purpose. These Military Characteristics define the Department of Defense (DOD) requirements for a warhead compatible with the Navy MK5A Reentry Body (RB) used on the TRIDENT II (D-5) Submarine Launched Ballistic Missile Weapon System. This warhead will be a replacement for the existing W88 warhead.

(U) 1.2 Contingencies. Should it appear impractical to meet any of these characteristics or should it appear that meeting of any criterion specified herein will unduly delay development or production of this warhead, or require unreasonable amounts of critical material, or incur unreasonable costs, prompt notification shall be made to the NWC.

(U) 1.3 Competing Characteristics Criteria. As a general rule, priority of consideration shall be given to nuclear safety, reliability and other operational characteristics, in that order. It is understood that technical feasibility, schedule and cost are to provide the basis for making tradeoffs among the desired competing characteristics.

(U) 1.4 Development Schedule. The warhead development schedule shall support an Initial Operational Capability of no earlier than the late 1990's.

(U) 1.5 . Design Philosophy. Attention must be directed toward a design that offers high reliability in a device that will remain in the strategic arsenal well into the next century. Warhead design should be conservative and should not attempt to extend performance beyond well established regimes. More specifically, the warhead design which is developed for this system should:

- (U) Minimize the likelihood of deleterious changes during stockpile life.
- (U) Enhance insensitivity to any changes that may occur.
- (U) Optimize the capability to replicate the design should a warhead rebuild program be required in the future.
- (U) Incorporate new modern safety features to the extent feasible consistent with yield, range and reliability requirements.

- (U) Meet the MC requirements while minimizing the dependence on underground nuclear tests and flight tests, both for development and stockpile surveillance.

- (U) Maximize compatibility with existing DOD hardware (including the AF&F) and facilities.

- (U) Optimize the producibility of the design consistent with potential limited weapon production capabilities.

2. (U) REENTRY BODY/WARHEAD TRADEOFFS

(U) 2.1 General. During the course of development, tradeoffs among competing reentry body/warhead characteristics shall be made with the guidance of the Project Officers Group to optimize overall system performance. Tradeoffs that could significantly alter the ability to meet the Military Characteristics set forth herein shall require prompt notification to the NWC.

(U) 2.2 Yield.

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(U) 3.4.4 Arming. The warhead shall be designed to allow arming as late as practical in its planned flight trajectory.

(U) 3.4.5 Automatic Disarming Provisions. The warhead shall automatically disarm within 10 minutes if arming power is interrupted.

(U) 3.4.6 In the absence of arming and firing signals, the probability of nuclear detonation for normal and hostile environments specified in the STS shall not exceed:

(U) 3.4.6.1 One in 10^9 per warhead lifetime in the absence of warhead enabling stimuli*.

(U) 3.4.6.2 One in 10^6 per occurrence after application of initial enabling stimuli and in the absence of final enabling stimuli.

(U) 3.4.7 The probability of a nuclear detonation in the abnormal environments specified in the STS shall not exceed:

(U) 3.4.7.1 One in 10^6 per exposure or accident in the absence of warhead enabling stimuli.

(U) 3.4.7.2 One in 10^3 per occurrence after application of the initial enabling stimuli but prior to final warhead enabling stimuli.

(U) 3.4.8 HE Safety. The following are design requirements:

(U) 3.4.8.1 The warhead HE shall not ignite or detonate as a result of a free fall of the RBA from a distance specified in the STS.

(U) 3.4.8.2 The warhead HE shall not detonate when the RB is subjected to the fire environments described in the STS.

(U) 3.4.9 Criticality. Warhead arrays shall remain subcritical in all planned configurations and abnormal situations stated in the STS.

(U) 3.4.10 Warhead Monitoring. A positive means of monitoring WH disablement status shall be provided.

---

* (U) The enabling stimuli are generally unique signals or environments that operate safety subsystems. They are selected during weapon system development such that they will not be duplicated or simulated by abnormal environments.

MILITARY CHARACTERISTICS FOR THE WARHEAD FOR THE TRIDENT I AND II MK4A REENTRY BODY (U)

1. (U) GENERAL

(U) 1.1 Purpose. These Military Characteristics define the Department of Defense (DOD) requirements for a warhead compatible with the Navy MK4A Reentry Body (RB) used on the C4 and D5 Fleet Ballistic Missile Weapon Systems (TRIDENT I & II). This warhead will be a replacement for the existing W76 warhead.

(U) 1.2 Contingencies. Should it appear impractical to meet any of these characteristics or should it appear that meeting of any criterion specified herein will unduly delay development or production of this warhead, or require unreasonable amounts of critical material, or incur unreasonable costs, prompt notification shall be made to the NWC.

(U) 1.3 Competing Characteristics Criteria. As a general rule, priority of consideration shall be given to nuclear safety, reliability and other operational characteristics, in that order. It is understood that technical feasibility, schedule and cost are to provide the basis for making tradeoffs among the desired competing characteristics.

(U) 1.4 Development Schedule. The warhead development schedule shall support an Initial Operational Capability of no earlier than the late 1990's.

(U) 1.5 Design Philosophy. Attention must be directed toward a design that offers high reliability in a device that will remain in the strategic arsenal well into the next century. Warhead design should be conservative and should not attempt to extend performance beyond well established regimes. More specifically, the warhead design which is developed for this system should:

- (U) Minimize the likelihood of deleterious changes during stockpile life.
- (U) Enhance insensitivity to any changes that may occur.
- (U) Optimize the capability to replicate the design should a warhead rebuild program be required in the future.
- (U) Incorporate new modern safety features to the extent feasible consistent with yield, range and reliability requirements.
- (U) Meet the MC requirements while minimizing the dependence on underground nuclear tests and flight tests, both for development and stockpile surveillance.
- (U) Maximize compatibility with existing DOD hardware and facilities.
- (U) Optimize the producibility of the design consistent with potential limited weapon production capabilities.

2. (U) REENTRY BODY/WARHEAD TRADEOFFS

(U) 2.1 General. During the course of development, tradeoffs among competing reentry body/warhead characteristics shall be made with the guidance of the Project Officers Group to optimize overall system performance. Tradeoffs that could significantly alter the ability to meet the Military Characteristics set forth herein shall require prompt notification to the NWC.

([redacted] 2.2 Yield.

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[redacted] 2.3 Physical Characteristics.

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3. (U) FUNCTIONAL CONSIDERATIONS

(SFRD) 3.1 Fuzing Options. The warhead shall be compatible with the fuzing options of air burst, near surface burst, and contact burst.

(U) 3.2 Environmental and Survivability Considerations

(U) 3.2.1 Normal Environments. The warhead shall be able to withstand the normal environments stated in the Stockpile-to-Target Sequence (STS) and meet the reliability stated in Paragraph 3.3 and the premature probabilities stated in Paragraph 3.4.6.

(U) 3.2.2 Hostile Environments. In addition to the normal environments, the warhead shall be capable of surviving the hostile environments stated in the STS and a) meet the premature requirements stated in Paragraph 3.4.6 and b) perform without severe degradation of the reliability stated in Paragraph 3.3.

(U) 3.2.3 Abnormal Environments. The warhead shall be able to withstand the abnormal environments stated in the STS and meet the premature probabilities stated in Paragraph 3.4.7.

(U) 3.2.4 Fratricide Environments. In addition to the normal environments, the warhead shall be capable of surviving the fratricide environment stated in the STS and perform without severe degradation of the reliability stated in Paragraph 3.3.

[redacted] 3.3 Reliability Considerations.

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(U) 3.4 Safety Considerations. Nuclear weapons safety must be the maximum achievable consistent with operational requirements.

[redacted]

(U) 3.4.1 In the event of a detonation initiated at any single point in the high explosive system, the probability of achieving a nuclear yield greater than four pounds TNT equivalent shall not exceed one in 10^6. This characteristic shall be inherent in the design and achieved without the use of mechanical safing devices.

(U) 3.4.2. The potential for dispersal of hazardous materials shall be minimized by design and operational procedures.

(U) 3.4.2.1 The warhead design shall incorporate modern safety features which minimize plutonium dispersal in fire and other abnormal environments as defined in the STS.

(U) 3.4.3. Multiple independent safety subsystems shall be incorporated that will prevent arming of the warhead firing system in any manner other than the prescribed warhead arming sequence. A positive interruption in the sequence of events necessary to cause warhead firing system arming shall be provided and shall remain effective until the warhead senses a unique environment subsequent to launch. This interruption may be provided by the arming and fuzing subsystem.

(U) 3.4.4. Arming. The warhead shall be designed to allow arming as late as practical in its planned

(U) 3.4.6 In the absence of arming and firing signals, the probability of nuclear detonation for normal and hostile environments specified in the STS shall not exceed:

(U) 3.4.6.1 One in 10^9 per warhead lifetime in the absence of warhead enabling stimuli*.

(U) 3.4.6.2 One in 10^6 per occurrence after application of initial enabling stimuli and in the absence of final enabling stimuli.

(U) 3.4.7 The probability of a nuclear detonation in the abnormal environments specified in the STS shall not exceed:

(U) 3.4.7.1 One in 10^6 per exposure or accident in the absence of warhead enabling stimuli.

(U) 3.4.7.2 One in 10^3 per occurrence after application of the initial enabling stimuli but prior to final warhead enabling stimuli.

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* (U) The enabling stimuli are generally unique signals or environments that operate safety subsystems. They are selected during weapon system development such that they will not be

APP. C ACCIDENT RESISTANT CONTAINER

APPENDIX C

ACCIDENT RESISTANT SHIPPING AND STORAGE CONTAINER (U)

Sandia National Laboratories
Livermore, California

(This Page is UNCLASSIFIED)

(U) Appendix C Accident-Resistant Shipping and Storage Container

(U) List of Acronyms and Abbreviations

b(3)
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DOE

(U) All of the MK4A candidates are compatible with the H1333A and H1333B MK4 RBA Shipping and Storage Containers. With an adapter, the MK4A designs are also compatible with the MK5 container. Therefore, we designed a single container which would accommodate either the MK5A or the MK4A.

(U) Because there are no formal accident resistance requirements for nuclear weapons, for the purpose of this study, we chose some criteria which we considered to be reasonable, as design goals. These design goals could be modified if a reason to do so arose. The design goals we chose are shown in Table C-1.

(U) Our main objectives in selecting these criteria was to assure:
- the exclusion barrier(s) remained intact as long as possible for IND safety;
- the fire resistance of the design would not be degraded by the accident (such as would occur if the FRP were punctured); and
- the entire weapon would remain as one unit and would not be dispersed over a broad area.

(U) Because our candidates have relatively good thermal resistance (fire-resistant pits (FRP) and good thermal weaklinks against IND) but have relatively limited mechanical resistance (which can negate the FRP and bypass IND safety subsystems), we concentrated primarily on providing as much mechanical protection as possible within the footprint and height of the H1514 Container. Designing to fit within the footprint of the existing H1514 container helps maintain compatibility with operations in the storage magazines and service units. The height is limited by the DOE SSTs and SGTs.

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Figure C-2 is a sectional view of the container with a MK5 RBA. Figure C-3 identifies the major components and materials.

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(U) Figures C-6 through C-8 illustrate the clearance between the RBA and the inner surface of the container required to accommodate the RBA lifting and mating fixture ("Four Poster"). This clearance limits the thickness of accident mitigating materials that can be used.

(U) The accident-resistance capabilities of this container are significantly greater than those currently provided by the MK4 and MK5 Shipping and Storage Containers. However, the desire to keep the new container within the existing footprint limits the new container accident resistant capabilities to less than those of DOE's state-of-the-art H1501 Transportation Accident-resistant Container. The H1501 is shown in Figure C-9. The capabilities of the H1501 and the proposed MK5A accident resistance criteria are summarized in Figure C-10. The proposed MK5A criteria cover almost 90 per cent of aircraft accidents.

(U) A MK5A container with H1501 capabilities would be larger and heavier than the proposed design. Also, the H1501 is designed to carry warheads with their long axis oriented horizontally. Either the container would have to be redesigned to orient its long axis vertically or the MK5 and MK4 would have to be qualified for shipment with their long axes horizontal. Because of these considerations and our evaluation that the increased accident resistance was not sufficient to offset the associated drawbacks, we did not pursue the option of achieving the state-of-the-art in accident resistance. This assumes that these weapons will not be transported by air and therefore will not be exposed to the risk of an aircraft crash environment (high speed impact followed by a long duration fuel fire). If the weapon is to be transported by aircraft, then we would strongly recommend the development and use of an H1501A-like container to provide maximum protection in the event of an accident.

TABLE C-1

(U) PROPOSED ACCIDENT-RESISTANT SHIPPING CONTAINER DESIGN GOALS

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TABLE C-2

(U) DIMENSIONS OF STATE-OF-THE-ART ACCIDENT RESISTANT CONTAINER

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(U) Preliminary structural analysis indicates that the container meets the puncture and impact criteria. The area of most concern for impact is the bolted connection between the upper and lower pieces. This joint will require much more detailed design, analysis, and test to be qualified for these environments. The analysis also indicates that an 0.090 inch thick 304 stainless steel skin is adequate for these criteria. Thicker skin may not be beneficial--the skin would be stronger, but this increase would be offset by higher impact energies in the impact and puncture tests due to the increased weight of the skin.

(U) Preliminary thermal analysis of the proposed accident-resistant container indicates approximately a 10°F temperature rise from the ambient temperature to the outside surface of the RB during normal environments. In an abnormal thermal environment (1850°F fuel fire) the warhead IHE will not reach 319°F (the temperature at which it begins to react exothermically) for at least 50 minutes.

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Side View (Castors Extended)

End View (Castors Retracted)

FIGURE C-9
(U) H1501 TRANSPORTATION ACCIDENT RESISTANT CONTAINER

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SANDIA REPORT SAND82–2436 • RS3151/83/005 • Nuclear Weapon Data
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PAL Control of Theater Nuclear Weapons (U)

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FOR ORG 3141

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Prepared by
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Albuquerque, New Mexico 87185 and Livermore, California 94550
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under Contract DE-AC04-76DP00789

Classified by J. R. Caruthers, Supervisor, Command and Control Systems Division 5134, November 30, 1983

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2ND REVIEW-DATE: 5/25/96	3. CONTAINS NO DOE CLASSIFIED INFO
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incorporated in dispersed weapons can be made solely in terms of broad policy considerations as to the desired objective."

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1.3.1.2 PAL General Characteristics (U)

(U) In September 1962, the Secretary of Defense approved a set of DoD design guidelines for PAL systems. These guidelines, entitled "General Characteristics for Permissive Devices for Use With Nuclear Weapons," or revisions thereof have served since that time as standards in specifying PAL devices in the MC of new weapons systems. The original guidelines and the four revisions (1969, 1970, 1972, and 1980) are included in Appendix B.

(U) The statement of purpose in the first edition of the General Characteristics of PAL defines:

> (U) "an arming control device for use with designated nuclear weapons which is intended to provide some additional physical means for preventing unauthorized use of nuclear weapons."[18]

(U) A number of specific design requirements are included. Most of these relate to specific operational features of the PAL system or to issues of compatibility with the rest of the weapons system. For instance, the PAL system

- (U) must not degrade weapon safety or reliability
- (U) must he compatible with weapon operational concepts as stated in the STS
- (U) must not significantly lengthen the reaction time for the weapon system

(U) These requirements are restated in all subsequent versions of the General Characteristics. However, as suggested in the Weisner memo, the objective of this system and its reason for existence is based on its ability to protect the weapon against unauthorized use by a potential adversary. Of the twelve specific design requirements stated in the original document, only one relates to the performance of PAL against an adversary.

[redacted]

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(U) Thus, the objective in terms of an adversary is not specified. However, some bounds are placed on the adversary's capabilities. The *function* of PAL is stated in terms of delay following unauthorized access to a weapon.

(U) In the 1969 edition, the stated purpose is

(U) "To provide general characteristics for permissive action links incorporated in weapons systems to prevent unauthorized nuclear detonation."[19]

[redacted]

DOE b(3)

C b(1)

(U) In 1972, a new edition was prepared to include all existing PAL technology. While the statement of purpose remained essentially the same as in the 1969 edition, PALs are defined as

> (U) "devices and subsystems designed to reduce the possibility of obtaining a nuclear detonation from a nuclear warhead without the use (insertion) of a controlled numerical code, thus reducing the probability of an unauthorized nuclear detonation."[20]

DOE b(3)



Figure 4. M77 Atomic Weapon Locking Device (U)

(U) The W79 8-in. AFAP preceded the W84, entering Phase 6 production in September 1981. Ultimately the W79 will replace the W33 8-in. projectile in stockpile. However, a date for overseas deployment is uncertain at this time. The W79 is equipped with the MC2907 MCCS that provides CAT D PAL protection.

(C) The W85 PII warhead begins Phase 6 production in May 1983. Eventually, the improved PII system will replace many PIs presently deployed to NATO. The W85 is basically a B61-4, CAT F warhead adapted to the warhead section of the PII missile. As such, it is equipped with an MC2907A MCCS.

(C) The W82 155-mm AFAP that will replace the W48 projectile is presently scheduled to enter Phase 6 production in June 1986. No deployment date has been announced. The W82 will be equipped with the MC3764 CAP (Section 4.2). The CAP will provide the same multiple code population and limited-try features as the MCCS, but the W82 will not be maintained in a disenabled state by interrupting warhead circuitry. Instead, the CAP will be located outside the weapon in a Use Denial Lock (UDL). The UDL (Figure 44) is a device which fastens to the nose of the projectile, preventing installation of the fuze. Unlocking the CAP allows removal of the UDL. An Integrated Control Unit (ICU) in the shipping container of each round will provide unlock and relock control of the UDL (Figure 45).

(U) A factory-rebuild program is currently under way to upgrade early versions of the B61. The B61-6 will result from retrofitting the B61-0 with enhanced safety features and the MC2907 CAT D PAL. First Phase 6 production is scheduled for October 1985. The B61-8 represents a safety upgrade of the B61-2 and B61-5. The B61-8 will have an MC2907 CAT D PAL and is scheduled for initial Phase 6 production in January 1988.

(U) Four strategic systems with PAL are planned for the stockpile. Two of these are modifications of existing systems. The B28 (Mods 0 and 1) will be field retrofitted (beginning April 1983); B61-1 will be factory rebuilt (Phase 6 begins September 1985) into the B61-7. Present plans call for an MC2907 CAT D PAL in both systems. Two new strategic systems, the W80-1 warhead for the Air-Launched Cruise Missile (ALCM) (Phase 6 production began February 1982) and the B83 modern strategic bomb (Phase 6 production is scheduled to begin September 1983), also will be equipped with the MC2907 CAT D PAL.

(U) Two new PAL-equipped Navy systems are currently planned. Both the W80-0 warhead for the Tomahawk Sea-Launched Cruise Missile (SLCM) (Phase 6 production is to begin April 1984) and the W81 warhead for the SM-2 fleet air defense missile (Phase 6 production to begin November 1986) will have CAT D PAL (MC2907 or MC3764).

(U) A stockpile projection[31] (Figure 46) shows the planned distribution of PAL-equipped weapons (weapons with no PAL are not shown) through FY 1992. This projection reflects the planned production of weapons equipped with modern CAT D and F PAL devices.

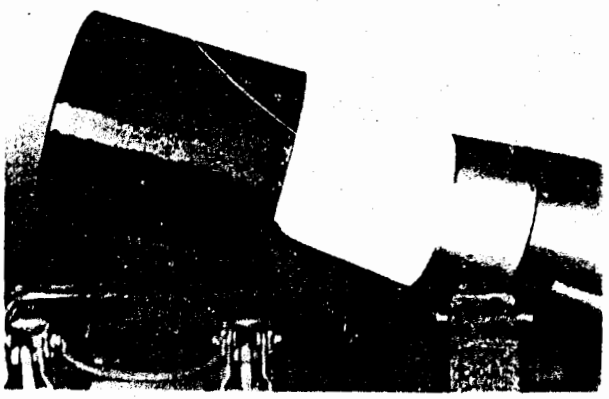


Figure 44. Use Denial Lock (U)

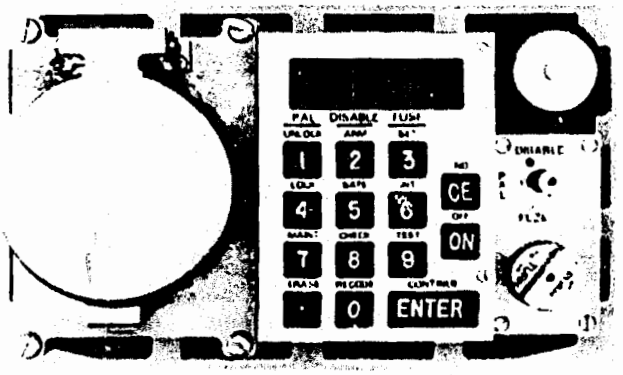


Figure 45. Integrated Control Unit (U)

(U) The HCP (Figure 47) is built around an HP 1000 computer. The system includes a printer, CRT display screen, keyboard, tape and disc storage units, and a cryptographic system. HCP operation is depicted in Figure 48. It has a number of functions. First, it provides access, under two-man control, to encrypted code information from the source data module generated by NSA. In addition, it contains a weapon data base that may be periodically updated.

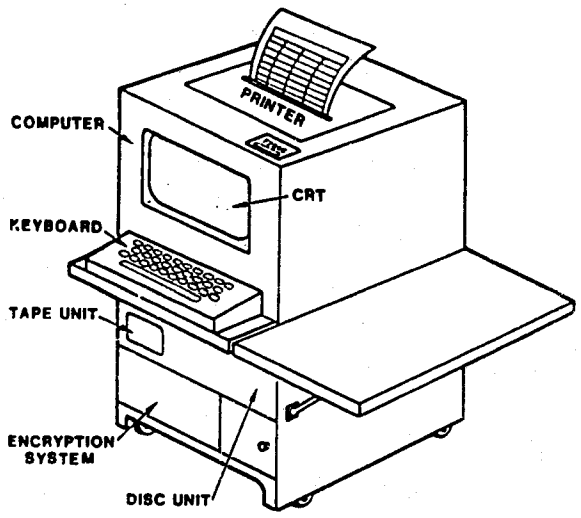


Figure 47. T1565 HQ Code Processor (U)

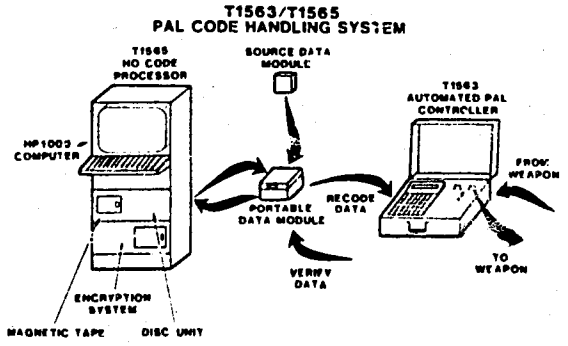


Figure 48. T1563/T1565 PAL Code Handling System (U)

This data base would include, for example, the theater weapon inventory information: mark and mod, serial number, and location of weapons in theater. Utility programs will be available for correlating the data base information with the weapon code information to aid in the construction of theater code plans. Given a theater code plan, the HCP will be able to generate the appropriate portable data modules for use by APCs during recode operations. The HCP will also be capable of reading monitor modules generated by the APC during recode. This may eliminate the need for on-site recode verification by the PMCT in cases where recode can be done with the APC.

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THE WHITE HOUSE
WASHINGTON

June 6, 1962

NATIONAL SECURITY ACTION MEMORANDUM NO. 160

TO: The Secretary of State
The Secretary of Defense
The Chairman, Atomic Energy Commission
The Director, Bureau of the Budget

SUBJECT: Permissive Links for Nuclear Weapons in NATO

1. After an examination of the problem of installing permissive links in nuclear weapons dispersed in NATO commands, I have decided we should now make the commitment to procure appropriate devices for all nuclear weapons, now dispersed and to be dispersed to NATO commands, for both non-U.S. and U.S. forces. (See attached memorandum to me from Dr. Wiesner dated May 29. This decision corresponds to Alternative 5 of that memorandum.)

2. This will require a supplementary appropriation for the Atomic Energy Commission budget. The Secretary of Defense, the Chairman, Atomic Energy Commission, and the Director, Bureau of the Budget will work out the details of the budget presentation.

3. At the earliest feasible time, the Secretary of Defense will submit for my approval a schedule for installation of these devices in NATO weapons. In making this schedule, the Secretary should consult with the Secretary of State on the political problems arising from the existence of weapons assigned to U.S. forces and weapons assigned to our Allies.

4. The Chairman, Atomic Energy Commission, in consultation with the Secretary of Defense, will carry out a research program on an urgent basis directed toward an examination of the feasibility and desirability of more advanced permissive link devices with a wider range of capabilities.

/s/ John F. Kennedy

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APPENDIX A

NSAM-160 and Wiesner Memorandum
Original Document Secret

MEMORANDUM FOR

THE PRESIDENT

At your request, I have reviewed, in consultation with the AEC and the DOD, the technical and cost aspects of equipping nuclear weapons dispersed overseas with permissive link hardware. The object of this review was to establish the program options that were technically available to implement such a program as rapidly as possible, and to determine the amount of supplemental funds that would have to be requested in the AEC FY '63 Budget to accomplish these options.

A decision on this problem involves the following basic policy issues which, while not technical in themselves, are affected by the availability of equipment and the program timing and cost:

(1) Should a permissive link be incorporated at this time in all dispersed nuclear weapons or just in those critical weapon systems with quick reaction, high yield and long range (e.g., Jupiter missiles and quick reaction aircraft)?

(2) Should a permissive link be incorporated at this time in all weapons dispersed to NATO (U.S. as well as non-U.S.) or just to non-U.S. weapons?

(3) Should a permissive link be incorporated at this time in weapons committed to NATO but based in the U.K. as well as weapons based on the European Continent?

These policy issues raised the more basic question as to what objective one is attempting to accomplish by incorporating a permissive link. A permissive link can attempt to meet any of the following objectives, each of which imposes increasingly difficult technical problems:

purpose of this review, I have not attempted to meet a specific objective but rather have analyzed the operational value of the best available equipment and attempted to determine how rapidly it could be incorporated in dispersed nuclear weapons.

While the permissive link equipment presently recommended by the AEC leaves something to be desired and can clearly be much improved with time, I believe that this equipment can be used as the basis for a crash program since development quality hardware exists and initial production and installation could begin in the immediate future.

Specifically the AEC recommends that, if a permissive link program is undertaken on a crash basis, bombs for aircraft and warheads for longer range missiles be equipped with an electro-mechanical lock which would have to receive a prearm numerical code in order to make the weapon operable. In the case of certain bombs which cannot be easily retrofitted with this equipment, as an interim measure pending the development of improved compatible permissive link hardware, mechanical combination locks would be installed to cover a socket into which an arming plug must be inserted. In the case of those bombs as well as short range missiles, such as Honest John and Mike Hercules, and the 8-inch shell, the arming plugs would be stored in self-destruct safes. The proposed program does not include specific hardware for the Davy Crockett missile which presents a particularly difficult problem because of its small size and possible forward deployment.

The numbers which would operate both the electro-mechanical and the combination lock could be held at any echelon or command. If circumstances required, the combination could be held by the U.S. custodial officer himself. This procedure could therefore give the weapons the same state of readiness that they now possess.

In evaluating the utility of this equipment, it must be recognized that it is simply intended to buy time. A specialist with proper equipment might be able to crack the electro-mechanical lock in a few hours time. If he were able to circumvent the self-destruct feature of a safe, a skilled locksmith could open a combination lock relatively quickly. In any event, it would also be possible for skilled technicians familiar with weapons to make these weapons operate in a period of from several hours to weeks, depending on the extent of thier knowledge, by opening the weapons and bypassing the electric circuits. Despite the limitations of this equipment, I believe it would give further (and probably decisive) protection against individual psychotics and would certainly cover unauthorized use by military forces holding the weapons during periods of high tension or military combat. While it would not assure that the weapons could not be used if they were forceably seized by an organized group or a foreign power with technically capable individuals, it would provide in the case of the more important weapon systems equipped with electro-mechanical lock a period of time, varying from hours to days, in which decisions could be made as to what our proper response to the seizure should be. The question of the legal and political requirements of control were beyond the scope of my review.

The question has been raised whether the installation of this development quality hardware on a crash basis might reduce the reliability of the nuclear weapons. However, in view of the simple nature of this equipment and the method of installation, I believe that it is now generally agreed that it would not reduce the inherent reliability of the weapons. The weapons would, of course, not be operable if the combination number were not received from a higher headquarters. This is a communication and management problem, which can be very simple or a very complex, depending on the level of command at which the combination number is held and the degree of control maintained through coding procedures or the use of different combination numbers for different weapons. In its simplest form, it should be possible to handle this procedure wherever a "go code" can be transmitted which is presently a requirement if any control is to exist. In any event, I wish to emphasize that, if circumstances demand, a decision can be made to release the combination number to the U.S. custodian with the field unit and thereby revert to the state of readiness and control that exists today.

At my request, the AEC has estimated the cost and time for completion of the following five alternative programs, which I believe represent the full range of possible application of the permissive link on a crash basis to nuclear weapons dispersed to the European Theater:

The estimated completion date, total cost, and FY '63 for each of these programs is as follows:

Alternative	Estimated Date Completed Installation	Total Cost ($ Millions)	FY '63 Cost ($ Millions)
I	June 1963	3.2	3.2
II	Oct. 1963	11.3	10.6
III	Dec. 1963	13.6	11.7
IV	Mar. 1964	18.6	13.8
V	Aug. 1964	26.9	14.0

A supplemental to the AEC FY '63 Budget would call for obligation of the total cost of the program but expenditure of only the FY '63 cost of the program.

On the basis of this review, I have concluded that it is technically possible to equip on a crash basis all nuclear-weapons dispersed to the European Theater with reasonably effective permissive link equipment at relatively small cost. Therefore, the decision as to the extent to which permissive link equipment should in fact be incorporated in dispersed weapons can be made solely in terms of broad policy considerations as to the desired objective.

Whatever decision is made on the crash program to install permissive link equipment on dispersed nuclear weapons equipment, I would recommend that a vigorous program be undertaken to develop an improved electronic lock which would be incorporated directly in the electronic package associated with all future weapons so that the option of a permissive link would always exist. This program should also include work to develop improved devices to retrofit the bombs and medium range missiles which were equipped with combination locks only as an interim measure in the above crash program. I would also recommend that there be an agressive research program to develop more advanced concepts of the permissive link including mechanics to assure the self-destruction of a weapon if efforts were made to by-pass the permissive link. It is my understanding that the AEC has funds available to cover the R&D necessary for these advanced programs.

Jerome B. Wiesner

APPENDIX B

General Characteristics for PAL Devices
Original Document Secret

Item I

GENERAL CHARACTERISTICS FOR PREMISSIVE DEVICES
FOR USE WITH NUCLEAR WEAPONS (U)

General Characteristics
Approved by the OSD:
13 September 1962

1. Purpose. These General Characteristics define an arming control device for use with designated nuclear weapons which is intended to provide some additional physical means for preventing unauthorized use of nuclear weapons.

2. General Characteristics. The device shall conform to the general characteristics and provide the capabilities listed below:

a. The device shall be capable of repeated enabling, disenabling, and recoding. Further, the device shall be capable of being maintained in either the enabled or disenabled mode.

b. When the device is enabled, a positive indication of enabled condition shall be provided. It is highly desirable that this indication provide no usable information to an unauthorized operator.

c. The time required for authorized enabling of the device shall not add to the weapon system reaction time under any readiness condition. Capability for inflight operation of this device is required for certain aircraft applications.

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b(3)

e. The device and associated equipment shall be designed so that inspection or disassembly of the weapon will not disclose the combination or code.

f. The combination or code shall be transmitable by all standard communications means, and shall be capable of being changed rapidly and accurately by persons having the appropriate equipment and the old combination or code.

g. The device shall be so located and shall function in such a manner that it will permit performance of the required weapon maintenance, retrofit, and test operation throughout the stockpile-to-target sequence, without enabling the device.

h. The device and associated equipment shall be of such quality as not to decrease significantly the weapon reliability.

i. The device and its associated equipment shall be designed so as to permit installation and use of the device in bombs or warheads without degrading weapon safety.

j. The device installed in the weapon itself should not degrade the delivery capability or alter the ballistics of the weapon system.

k. Meters, dials, and switches on device components which are used in the open without blackout protection shall be illuminated in such a manner that blackout will not be violated.

l. The device and its related equipment shall withstand, without functional impairment or reduction of operational reliability, the environmental criteria specified in the applicable stockpile-to-target sequence of authorized weapon applications and in assoicated environmental specifications.

5. Inspection & Maintenance.

a. The system shall be designed so that inspection or disassembly of any component external to the warhead will not disclose the codes.

b. The permissive action link shall be so located and the system shall function in such a manner that it will permit perormance of the required warhead maintenance, retrofit (including internal and external components exclusive of the permissive action link system), and test operations throughout the STS without changing the mode of the device.

c. The system shall be capable of having maintenance performed on it in either the enabled (unlocked) or disenabled (locked) mode.

d. The operational storage life of that portion of the system installed in the warhead shall be no less than that of other warhead components.

6. Control Equipment.

a. Control equipment with the exception of decoders installed in aircraft shall be designed to permit disenabling (locking) and enabling (unlocking) using the "two-man" concept, and recoding using the "two-team" concept.

b. Control equipment shall provide a positive indication of the mode of the permissive action link device. This indication should provide no information regarding the set code.

c. Decoders shall be capable of enabling (unlocking), disenabling (locking), and code checking.

d. Recoders shall be capable of recoding and code checking the system without enabling (unlocking) the device.

e. Design alternatives which combine decoders and recoders are acceptable.

7. Environmental Considerations.

a. Meters, dials, and switches on componenets which are used in the open without blackout protection shall be illuminated in such a manner that blackout will not be violated.

b. The system and its related equipment shall withstand, without functional impairment or reduction of operational reliability, the evironmental criteria specified in the applicable stockpile-to-target sequence of authorized weapon applications and in associated environmental specifications.

Item 3

GENERAL CHARACTERISTICS FOR
PERMISSIVE ACTION LINK SYSTEMS USED WITH NUCLEAR WEAPONS (U)
(Attachment to DDR&E Letter to Chmn, AEC, same subject, 31 Dec 1970.)
(Original Document Secret)

1. Purpose. To provide general characteristics for permissive action links incorporated in weapon systems to prevent an unauthorized nuclear detonation. This document is not intended to inhibit in any way development of improvements beyond the characteristics set forth.

2. General.

[redacted] DoE b(3)

b. The system shall provide for two modes, unlock and lock of the warhead by insertion of one 6-digit decimal code.

[redacted] DoE b(3)

d. The system shall not significantly degrade weapon reliability, nor shall it degrade safety, or delivery capability. The time required for unlocking the device shall not unduly add to the weapon system reaction time under any readiness condition.

3. System Operation.

a. The control equipment must provide visual indications of the status of the system. As a minimum, the equipment must indicate when (a) the number of unsuccessful unlocking attempts is zero, (b) the number of unsuccessful unlocking attempts is greater than zero but less than that required for lockout, and (c) the device is locked out.

b. The system shall be capable of recoding, unlocking or locking at any point in the STS:

(1) in the case of aircraft weapon systems, up to the time of taxi and/or aircraft launch; and enabling (unlocking) or disenabling (locking) after aircraft launch.

(2) in the case of projectiles, at any time up to the time of loading into the weapon breech.

(3) in the case of missile systems, up to the time of final prefire operations.

c. The code shall be capable of being changed rapidly and accurately by persons using the appropriate equipment. Changing of the code will be dependent upon possession of the old (existing) code.

d. At anytime prior to permanent lockout the feature which counts the number of incorrect tries shall reset to zero whenever the proper code is inserted.

e. The system shall be capable of a code check operation which will allow verification of the set code without changing the mode of the device.

4. System Compatibility and Reliability.

a. The system shall be compatible with the weapon operational concepts to include the readiness requirements stated in the STS.

b. The system will be compatible with normal logistical movement in either selected mode.

c. The system shall be electrically compatible with other weapons system circuitry. In the case of aircraft systems it will be compatible with aircraft circuitry during all phases of circuit operation, both ground and air.

d. The design of control equipment shall preclude permanent locking if a permissive action link operation is interrupted by power failure.

e. The system shall incorporate a means of determining electrically, by a T-304 or similar service continuity test equipment, whether the permissive action link device in the unlocked condition.

[redacted] UNCLASSIFIED

Item 4

GENERAL CHARACTERISTICS FOR
PERMISSIVE ACTION LINK SYSTEMS USED WITH NUCLEAR WEAPONS
(Attachment to DDR&F Letter to Chun, AEC, Same Subject, 26 July 1972)
(Original Document Secret)

1. Purpose To provide general characteristics for AEC-produced electromechanical/electronic permissive action link (PAL) systems used with nuclear weapons to prevent an unauthorized nuclear detonation. This document is not intended to inhibit in any way development of improvements beyond the characteristics set forth.

2. Nomemclature

[redacted]

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3. Definitions

Permissive Action Link (PAL) – A family of devices and subsystems designed to reduce the possibility of obtaining a nuclear detonation from a nuclear warhead without the use (insertion) of a controlled numerical code, thus reducing the probability of an unauthorized nuclear detonation.

Passive Protection – Precludes operation of weapon arming circuits.

Active Protection – Senses attempts to gain unauthorized access to weapon arming circuits, with option to respond by initiating weapon disablement.

Mode – Refers to the protected condition (LOCK) or the unprotected condition (UNLOCK) of the PAL.

State – Refers to the condition of the active protection feature (OFF/TEST/ON).

Unlock Code – A preset code used to unlock the PAL.

Off Code – A preset code used to change state of OFF.

Code Check – Confirms stored code(s) in PAL without affecting weapon PAL mode.

Recode – Allows changing of stored code(s) in PAL.

Code Inhibit – Precludes a second unlock of a PAL with a given code until recode.

Limited-Try – Counts consecutive incorrect code trials and resets to zero on a correct code trial.

Temporary NO-GO – Precludes additional code trial operations without special field equipment after a number of incorrect code trials.

Permanent NO-GO – Precludes additional code trial operations with field equipment after additional incorrect code trials.

4. General Characteristics

A. Category A and Category B [redacted]

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2. These systems shall provide for two modes, UNLOCK and LOCK of the PAL by insertion of one 4-digit decimal code.

[redacted] UNCLASSIFIED

B. Category B'

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3. The system shall provide for two modes, UNLOCK and LOCK of the PAL by the insertion of one 4-digit decimal code.

C. Category C – The characteristics stated above (Category B') apply with the following modifications:

1. The system shall provide for two modes, UNLOCK and LOCK of the PAL by insertion of one 6-digit decimal code.

D. Category D

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C. (U) All Categories

(U) 1. The system shall be compatible with the weapon operational concepts to include the readiness requirements stated in the STS.

(U) 2. The system shall be compatible with normal logistical movement in any selected mode.

(U) 3. The system shall not significantly degrade weapon reliability, safety or delivery capability. The time required for unlocking the device shall not unduly add to the weapon system reaction time under any readiness condition.

(U) 4. The system shall be capable of being recoded, code checked, unlocked or locked at any point in the STS up to:

a. (U) In the case of missile systems, up to the time of final pre-fire operations.

b. (U) In the case of aircraft weapon systems, up to the time of taxi and/or aircraft launch, with unlocking or locking after aircraft launch. However, recode is not required after weapon loading on aircraft.

(U) 5. The system shall contain a Master Recode feature to allow recoding of all stored codes using any one of the old codes which has not been inhibited.

(U) 6. The system shall be capable of being recoded rapidly and accurately by persons using the appropriate equipment.

4. (U) CONTROL EQUIPMENT

A. (U) All Categories

(U) 1. The system shall be electrically and mechanically compatible with the weapon system. In the case of aircraft systems, any equipment installed in the aircraft or associated with the weapon will be compatible with aircraft circuitry during all phases of aircraft operation, both ground and air.

(U) 2. The system shall incorporate a means of determining electrically, by service continuity test equipment, whether the PAL is in the unlocked condition.

(U) 3. The control equipment must indicate when (a) the number of unsuccessful trial attempts is zero; (b) the number unsuccessful code trial attempts is greater than zero but less than that required for NO-GO; and (c) the device is NO-GO.

(U) 4. Control equipment shall be provided that will:

a. (U) Allow recoding and code checking without unlocking the PAL.

b. (U) Allow recoding any one or all unlock and off codes using one not inhibited stored code.

c. (U) Allow code checking all stored codes in one operation or code checking any one of the stored codes.

d. (U) Allow unlocking and locking the PAL.

e. (U) Allow PAL unlocking and locking operations in an aircraft to be performed by a single individual.

(U) 5. New control equipment shall minimize potential TEMPEST, tampering, and bugging vulnerabilities. DoE b(3)

5. (U) INSPECTION AND MAINTENANCE

A. (U) All Categories

(U) 1. The system shall be designed so that inspection or disassembly of any component external to the warhead will not disclose the codes.

(U) 2. The PAL system shall function in such a manner that with the active protection OFF, warhead maintenance and test operations can be performed without changing the mode of the passive protection.

6. (U) ENVIRONMENTAL CONSIDERATIONS

A. (U) All Categories

(U) 1. The system and its related equipment shall withstand, without functional impairment or reduction of operational reliability, the environmental criteria specified in the applicable weapon stockpile-to-target sequence.

(U) 2. Meters, dials, and switches on components which are used in the open without blackout protection shall be illuminated in such a manner that blackout will not be violated.

APPENDIX C

Letter from J. P. Wade, Jr., to D. C. Sewell



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DEPARTMENT OF DEFENSE
MILITARY LIAISON COMMITTEE
TO THE
DEPARTMENT OF ENERGY
WASHINGTON, D.C. 20301

April 18, 1980

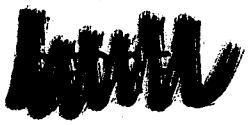
Honorable Duane C. Sewell
Assistant Secretary for
Defense Programs
Department of Energy
Washington, D.C. 20585

Dear Mr. Sewell:

(U) Over the past several months a great deal of concern and discussion has surfaced involving the policy for non-violent disablement and what role it should play in nuclear weapon security matters. Specific controversy has centered on questions of: which weapons should have a disable capability?; what level of sophistication should be credited to the threat?; and how long should disablement render the weapon useless against this threat? Department of Defense guidance to the Department of Energy in this area has been presented in systems Military Characteristics and POG meetings, as well as in the Nuclear Weapon Development Guidance. Unfortunately, in many cases it has been less than specific or subject to interpretation in application.

(U) I would like to clarify the existing situation and toward that goal, two transmittals are enclosed. The first is a DoD statement of policy addressing the goals and current assessment needs associated with nuclear weapon disablement systems. The second is a revision of the July 1972 "General Characteristics for Permissive Action Link Systems Used with Nuclear Weapons."

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(U) The paper "General Characteristics for Permissive Action Link Systems Used with Nuclear Weapons" should be viewed as the basic DoD definitions for PAL systems in acquisition of weapon systems incorporating DoE produced PALs. This paper, that supersedes the original 1972 document and amendments, will be forwarded to DNA for handling in a manner similar to weapon military characteristics, that is DNA will be responsible for publication and maintenance of an up-to-date file including amendments that may occur in the future. Consistent with our intention to work toward standardization of PAL devices and associated control equipment, only three PAL systems, Category D, E, and F are addressed in this update of the paper. Earlier PAL devices continue to remain in the stockpile: however, their acquisition cycle has been completed and therefore they have not been included in this update of the characteristics document.

Sincerely,

/s/ James P. Wade, Jr.
Chairman

Attachments
a/s (SFRD)

APPENDIX D

DoD Directive S-5200.16
September 22, 1970

APPENDIX E

JCS Pub 13, Volume II
(Excerpt From Chapter 7)

APPENDIX F

Excerpt From Amendment 3 to the Military Characteristics for a Nuclear Warhead for the 155 mm Howitzer Projectile (Approved by the MLC 27 April, 1971)

3. Control Devices

3.1 Security Container System (SCS)

An SCS, compatible with projectile and warhead designs, will be used with the M517 on an optional basis. The SCS will be developed under a program separate from the XM517 development program. The SCS shall be designed and function as specified in the SCS Characteristics attached as an Appendix.[2]

3.2. Permissive Action Link (PAL)

The PAL shall conform to the general characteristics outlined in the letter from the Director of Defense Research and Engineering to the Chairman of the Atomic Energy Commission, "General Characteristics for Permissive Action Link Systems Used with Nuclear Weapons," dated 31 December 1970.

3.2.1. The PAL control equipment shall also operate and be capable of recoding the SCS six-digit, limited-try coded switch.

3.2.2. It is desired that the control equipment be compatible with Category B, six-digit single code PAL devices.

3.2.3. The system shall provide for two modes, unlock and lock for the warhead by insertion of one six-digit decimal code. Unlock shall occur upon the insertion of any one correct code of six preset unlock codes. These unlock codes may be preset so that each is unique, or so that redundancies occur among them.

Edited by Wilma J. Bunker, Group S-4

Prepared by Petrita (Pat) Montano, Group S-4

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[redacted]

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[redacted]

GLOSSARY

ABM	antiballistic missile
ACM	advanced cruise missile (a conventional missile to be used by the Navy to attack surface ships from a submerged submarine)
AD/ADA	air defense/air defense artillery
ADM	atomic demolition munition
AEC	Atomic Energy Commission
AF&F	arming, fuzing, and firing
AFAP	artillery-fired atomic projectile
AICBM	advanced intercontinental ballistic missile
ALCM	air-launched cruise missile
ALWT	advanced lightweight torpedo
AMSAA	Army Materiel Systems Analysis Activity
AR	Army regulation
ARRADCOM	Army Armament Research and Development Command
A-Site	nuclear weapons storage site that contains weapons assigned to forward-based ground units
ASM	air-to-surface missile
ASP	ammunition supply point
ASTOR	antisubmarine torpedo ordnance rocket
ASW	antisubmarine warfare
ATSD(AE)	Assistant to Secretary of Defense for Atomic Energy

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BN	battalion
BTRY	battery (element of an artillery battalion)
C^2	command and control
CADMUS	controlled atomic demolition munition underground system

CASK	convertible antiship killer (a convertible conventional/nuclear missile to be used by the Navy to attack surface ships from a submerged submarine)
CD/CDS	command disablement/command disablement system
CEP	circular error probable
CFRD	confidential formerly restricted data
CNO	Chief of Naval Operations
CNW	convertible nuclear weapon (an INC weapon that has a nuclear capability when the SNM is emplaced and a valid conventional or chemical capability when the SNM is removed)
CNWDI	Critical Nuclear Weapon Design Information
CNSI	confidential national security information
COB	collocated operating base
COMP	component(s)
CONDOR	Navy air-to-surface missile
CONT	container
CONUS	Continental United States
CRD	confidential restricted data
CSWS	Corps Support Weapon System (recently merged into the Joint Tactical Missile system)
D^3	delay, disrupt, and destroy
D-38	depleted uranium
DEFCON	defense condition
DESTEX	a form of conventional HE
DNA	Defense Nuclear Agency
DoD	Department of Defense
DOE	Department of Energy
DT	deuterium-tritium
ED	emergency destruct
EOD	explosive ordnance disposal

LOADM	low-yield atomic demolition munition
MADM	medium atomic demolition munition
MGGB	modular guided glide bomb
MOB	main operating base
Modularity	general nuclear weapon design concepts that include insertable nuclear components, convertible nuclear weapons, and nuclear-only insertable nuclear components

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MRBM	medium range ballistic missile
MRR	minimum residual radiation
NATO	North Atlantic Treaty Organization
NCA	National Command Authority
NRC	Nuclear Regulatory Commission
NSC	National Security Council
NSI	national security information
NTS	Nevada Test Site
NUCL	nuclear
Nuclear-only weapon	An INC weapon that has only a nuclear capability. It is not designed to have a valid conventional capability when the SNM is removed.
NWDG	Nuclear Weapon Development Guidance
NWREP	nuclear weapon report
OCONUS	outside the continental United States
OPNAVINST	OPNAV instructions
OPS	operational effectiveness
OSD	Office of the Secretary of Defense
PACOM	Pacific Command
PAL	permissive action link
PBXN	form of plastic-bonded explosive used by the Navy

PRP	Personnel Reliability Program
PWW	planar wing weapon
QRA	quick reaction alert
RADM	radioactivity atomic demolition munition
RD	restricted data
RD&T	research, development, and testing
RV	reentry vehicle
RWC	removable weapon component
SACEUR	Supreme Allied Commander, Europe
SADM	special atomic demolition munition
SAFF	safing, arming, fuzing, and firing
SAM	surface-to-air missile
SLCM	sea-launched cruise missile
SLS	stockpile-to-launch sequence
SNC	separable nuclear component
SNM	special nuclear material
SNW	standard nuclear weapon
SOM	standoff missile
SOP	standard operating procedures
SRD	secret restricted data
S-Site	nuclear weapons storage site that provides storage for specifically assigned unit weapons and initial resupply weapons
SSM	surface-to-surface missile
STF	Special Task Force
S^3	safety, security, and survivability
STS	stockpile-to-target sequence
SWOP	special weapons ordnance publications
TASM	tactical air-to-surface munition

EXECUTIVE SUMMARY

A. Overview

A nuclear weapons stockpile that is totally survivable, secure, safe, and operationally effective with a light logistic burden, all obtainable at a cheap price, represents the ideal world for the military services. This, of course, is an impossibility. As the pendulum of requirements swings in the direction of greater safety and security, survivability necessarily suffers, the nature of the problem being a choice between Scylla and Charybdis.

DOD [redacted] We undertook this study to determine if modular weapon technology offers not a panacea, but a means of improving the overall utility of certain types of nuclear weapon systems. It was intended to produce an essential first-reference document useful in determining the feasibility and utility of modular nuclear weapons, including insertable nuclear components (INCs).

For certain tactical applications, safety is enhanced, and more importantly, this enhancement should allow evolutionary modifications to existing stockpile-to-launch sequences (SLSs) and to administrative regulations that can substantially improve nuclear weapon survivability in the European theater and allow for greater flexibility and operational effectiveness in special theaters.

B. Summary

We reviewed the studies that have addressed modularity, identified potenial requirements for modular weapons, examined the technology needed to support modular weapons development, identified potential applications of modular technology, and evaluated the overall utility of developing and deploying these candidate modular weapon systems.

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Although modular requirements have not been formally specified by the services, they have expressed varying degrees of interest in identifying the costs and benefits associated with incorporating modularity in the development of new tactical and strategic nuclear weapons.

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Ironically some of the earliest nuclear weapons in the stockpile incorporated INCs, then called in-flight capsules.

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The development of the sealed-pit weapons led to the demise of these early modular weapons around 1960. Technological advances plus increasing concerns for the survivability and security of the nuclear weapon stockpile led to a resurgence of interest in modular weapons during the 1970s that has continued to the present.

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Potential system applications for modular technology were evaluated in a matrix that compared families of weapon categories with 34 specific weapon system/warhead characteristics. The strongest contenders for modular technology are tactical systems, the most favorable being a land-launched tactical missile/cruise missile, either convertible or nuclear-only; sea-launched tactical missile/cruise missile, again either convertible or nuclear-only; and an air-launched tactical bomb or air-to-surface missile (ASM) with a nuclear-only capability. Other tactical candidates scored very well but were not selected for the utility analysis: artillery fired atomic projectile (AFAP), torpedo, ADM, and air-to-air missile. Within the strategic categories, the mobile ICBM [surface-to-surface reentry vehicle (RV)] appeared to be a reasonable candidate for modularity, but it was viewed as another good follow-on candidate in view of the political and operational problems associated with mobile strategic systems in the continental U.S. (CONUS) at this time.

[redacted]

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The utility analysis compared the advantages and disadvantages of modularity with three baseline systems in accomplishing tactical missions for each of the military services. All three candidates are high-value munitions and represent small buys.

- The Army mission analyzed is two-fold:

DOD [redacted] and provide conventional and possibly nuclear air-defense (AD) coverage at medium and high altitudes. The baseline systems are Lance, Hawk, and Nike-Hercules. The generic modular candidate is a convertible surface-to-surface missile/surface-to-air missile (SSM/SAM) system.

- The Navy's mission is to defeat enemy ships, submarines, and shore installations using the [redacted] as the baseline conventional system, and a convertible modular system [redacted] as the modular candidate.

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- The Air Force's mission parallels the Army's first mission of [redacted] the family of B57 and B61 gravity bombs make up the baseline. A dedicated force of nuclear-only TASMs is the candidate modular system.

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[redacted]

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A secure container with permissive action link (PAL) and command disable (CD) features protects the INC before insertion. The warhead body (WHB) contains the electrical interconnects to the missile guidance system and holds the IHE (or DESTEX for the Navy candidate) necessary to implode the pit. It does not contain RD information. The convertible applications also contain the unitary conventional high explosive (HE) or submunition explosives (or chemicals) in its remaining volume.

The major advantages and disadvantages of modularity as shown by the utility analysis are summarized in the section below. One important caveat t d t d' d 'athenrevs f service regulations in Chapter VI tT

[redacted]

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The advantages and disadvantages are listed below; the service candidate affected is in parentheses.

Pro: (1)

(2)

(3)

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(4)

(5)

Con: (1)

2. Security. Security is a condition that results from the establishment of measures to protect designated information, personnel, systems, components,

and equipment against hostile persons, acts, or influences. Several technical and operational advantages accrue to modular warheads.

DOD

Pro: (1) Command and control requirements are now on components that are individually unable to produce a nuclear yield. (All three candidates)

(2)

(3)

DOD

(4)

Con: (1)

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(2) Peacetime dispersal to using units (Army) or deployment during crisis/hostilities to collocated air bases or strips (Air Force) for increased survivability means:

a. Exposure to more personnel.

b. Storage at less secure areas than the baseline unless storage wells or shelters are provided.

3. Safety. Safety enhancements are inherent within the INC technologies, regardless of whether or not a favorable administrative and regulatory environment evolves. Two types of safety are analyzed in this report: nuclear detonation safety where an inadvertent detonation gives a nuclear yield in excess of 4 lb HE equivalent, and plutonium-scatter safety where detonation of the HE results in dispersion of plutonium.

Modern nuclear weapons are safe from accidental nuclear detonation, especially those containing IHEs--the U.S. has a perfect record. However, modular warheads are safer before insertion because the INC is physically separated from the HE. The probability of an accidental nuclear yield is zero. Though IHE has greatly reduced the probability of future plutonium

dispersal accidents with standard nuclear warheads, an accident involving the movement of a WHB (less INC) cannot disperse plutonium (it has none); an accident involving an INC would have a much lower probability of plutonium dispersal because of substantially reduced HEs.

Pro: (1) Separation of explosives from nuclear material inherently increases nuclear detonation safety. (All three candidates)

a. Before insertion, modular warheads are safer than the baseline nuclear warheads.

b. After insertion, modular warheads are as safe as baseline nuclear warheads.

(2) Accidents involve lower probabilities of plutonium dispersal. (All three candidates)

(3) Intrinsic radiation concerns can be lessened by storing INCs in shielded containers. (Navy)

a. The INC is stored and transported in strong secure containers with only a small amount of IHE.

b. The WHB body is devoid of plutonium.

Con: (1) Intrinsic radiation concerns are increased because of greater amounts of SNM in INCs if shielding is not adequate. (Navy)

4. Operational Effectiveness. Operational effectiveness as used in the analysis includes mobility, targeting flexibility, enduring capability, storage flexibility, nuclear yield, conventional warhead effects, reliability, range, and foreign political acceptability. The three candidates generally offer improvements over the baseline systems in this area.

Pro: (1) Strategic and tactical mobility for European and special theaters are increased because of the small size and weight of INCs and lack of nuclear materials in the WHB. (All three candidates)

(2) Convertible weapons can provide tremendous targeting flexibility. (Army, Navy)

(3) Enduring capability is available through the rapid logistic resupply of INCs. We think that early dispersal of the missiles and the non-RD WHBs to their field locations will substantially increase their survivability. (All three services)

(4) Convertible weapons allow full nuclear or conventional capabilities where storage areas are limited. (Navy)

Con: (1) Hard fixed-target requirements may necessitate a large and heavy two-stage INC. (Army, Air Force)

(2) Convertible weapons may incur reduced conventional effectiveness because of WHB volume devoted to the nuclear application. (Army, Navy)

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(3) [redacted] This can be minimal with high production standards, affordable because of the small weapon system buys, and fully acceptable especially in insertion operations within a clean environment. (All three candidates)

(4) Range for the nuclear mode of convertible weapons may be less. (Army)

Unknown: (1) Foreign political acceptability of storing, docking, or overflying INCs and/or WHBs (without INCs) is unclear in areas currently restricted to nuclear weapons. (All three candidates)

5. Logistics. We examined the following subareas: transportation and handling, maintenance and support, storage requirements, special theater movements, training, limited-life component exchange (LLCE), administrative and security regulations, component classification, security personnel, and personnel reliability and inspections. Throughout we used the SLSs that were defined under a favorable environment where the missiles and WHBs do not require RD protection.

Pro: (1) [redacted] DOD DOE b(3)

(2) Size of storage areas requiring special nuclear protection is decreased. (All three candidates)

(3) Training in unit areas and in the field can improve because of the greater availability of INC mock-up trainers and non-RD WHBs. (All three candidates)

(4) Transportation of INCs into special theaters can be more rapid and secure than that of full-up nuclear munitions. (All three candidates)

(5) Limited-life component exchange is easier. (All three candidates)

(6) Maintenance and support workload and handling equipment are reduced for the INC. (All three candidates)

Con: (1) Administrative and security regulations must be adapted to engender viability of modular weapons in all utility areas (except safety, which is inherently increased). (All three candidates)

(2) The WHB must not carry a classification higher than its delivery missile. (All three candidates).

(3) Numbers of security personnel will generally be unchanged unless current storage sites become INC-only sites. Security personnel requirements and storage sites will increase if unit storage is allowed. (Army, Air Force)

Unchanged: (1) Requirements for personnel reliability programs and inspections will probably remain the same. (All three candidates)

(2) Limited-life component exchange intervals and stockpile life will remain the same. (All three candidates)

6. Costs. Life cycle costs including development, production, and operation and support categories were examined in a relative context. Though absolute cost numbers were not estimated, the merit assessment establishes the broad cost trends.

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The Army and Air Force modular candidates are estimated to cost more, primarily because of increases in production, security, and storage costs. However, transportation costs are singled out as a category where substantial cost savings should be realized.

Pro: (1) Costs of a convertible warhead force are less than the costs of a dedicated nuclear plus dedicated conventional force. (Navy)

Con: (1)

DOD 6(3)

(2)

DOD

(3) Production of safe, secure containers and construction of associated storage facilities may be expensive, particularly for the Army system. (All three candidates)

Unknown: (1) Missile system operation and support costs account for about

fifty percent of weapon total life cycle costs. (If delivery unit life-cycle costs are considered, then the costs of INCs become practically negligible in terms of total life-cycle costs.) Costs may rise in certain areas, and fall in others. The overall effect is highly dependent upon INC storage schemes and security regulations, especially for the Army system. (All three candidates)

D. Recommendations

DOD

(1)

(2) Recommend that the Laboratory continue to develop concepts for engineering designs to support modular systems in support of identified or perceived service requirements.

(3) Finally, based upon specific service stated requirements, recommend that the Laboratory be prepared to develop modular warheads for production and deployment.

[redacted]

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MODULAR WEAPON SYSTEMS AND INSERTABLE NUCLEAR COMPONENTS

A Compendium of Requirements, Technology, Applications, and Utility (U)

by

Joseph S. Howard II, Edward J. Palanek, John L. Richter, Richard R. Sandoval, Frank L. Smith, Richard H. Stolpe, CDR Larkin E. Garcia, LTC L. Warren

ABSTRACT (U)

This document is to serve as an essential first reference in determining the applicability and utility of modular nuclear weapons, including insertable nuclear components. Potential requirements for modular weapons were identified, past studies were reviewed, and warhead technologies needed to support weapons development were examined. The most promising of the potential applications of modular technology were evaluated in a utility analysis that covered survivability, safety, security, operational effectiveness, logistics, and costs. These analyses indicated potential utility of certain tactical modular applications. Recommendations are made that support continued Los Alamos development work.

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CHAPTER I

INTRODUCTION

A. Purpose

The purpose of this study is to identify potential requirements for modular nuclear weapons, to review the technology needed to support modular weapons development, and to determine the feasibility, advantages, and disadvantages of developing and deploying one or more generic modular weapons in support of identified service missions.

B. Scope

The scope of this study includes:

- Defining modularity and various system configurations that constitute modularity and other pertinent terms required for understanding the subject area and this study (Chapter I and Glossary).
- Reviewing previous and on-going studies that address modularity and identifying the potential sources of requirements for development and deployment of modular weapons (Chapter II).
- Reviewing modular technology to include the advantages and disadvantages of implementation of the technology (Chapter III).
- Identifying potential applications of modular technology in terms of generic systems and applicable missions (Chapter IV).
- Evaluating potential applications in terms of operational effectiveness: safety, security, and survivability (S^3); design limitations; and cost effectiveness (Chapter V).
- Reviewing publications and regulations that affect the development and deployment of modular weapons (Chapter VI).

C. Objective

The objective of this study is to bring together in one comprehensive document the previous and current work that has been accomplished in the area of nuclear weapon modularity, to evaluate modular technology applications to the missions and requirements of the armed services, and to determine the political and regulatory restrictions that apply. It is intended that this document will serve as an essential first reference in determining whether

modular technology for future weapons should be pursued, identifying weapon types and missions that might use modular technology, and postulating the political and regulatory restrictions that must be overcome.

D. Definition of Terms

Many terms have been used to define the concepts associated with weapons that have alternative warheads or require procedures to ready a complete warhead. In this study, we attempt to establish a set of distinct terms that define the entire spectrum of modularity concepts used here. Other terms used in the study are listed in the glossary.

Modularity - A nuclear weapon design concept that includes insertable nuclear components (INCs), convertible nuclear weapons, and nuclear-only INC weapons.

INC Weapon - A nuclear weapon design concept whereby a nuclear capable warhead can be converted from a nuclear-inert to a live nuclear warhead by inserting a nuclear component. There are two general subclasses of INC warheads: convertible warheads and nuclear-only warheads.

Convertible INC Weapon - An INC weapon that has both a nuclear capability when the special nuclear material (SNM) is emplaced, and a valid conventional or chemical capability when the SNM is removed.

Nuclear-Only INC Weapon - An INC weapon that has only a nuclear capability. It is not designed to have a valid conventional capability when the SNM is removed.

From the definitions above we see that there are two subclasses of INC warheads: (1) convertible warheads and (2) nuclear-only warheads. A convertible warhead is basically a conventional high-explosive (HE) warhead modified so a nuclear assembly, generally called an INC, can be inserted to give the weapon an optional nuclear yield. Convertible warheads may thus have either a nuclear yield or a useful conventional HE yield. With this option, the field commander can choose the yield (either nuclear or conventional) best suited to the delivery system, the battlefield conditions, and the target. Convertible INC designs may make many training and operational requirements

cheaper and simpler because the user need concern himself with just one basic weapon system instead of two. The nuclear-only INC design is used only with a nuclear yield. With either type, the nuclear assembly (the INC) is stored away from the basic weapon most of the time. The INC is inserted only after National Command Authority (NCA) release and, ideally, only after a target is at hand. During almost all the stockpile-to-target sequence (STS), the user does not have a nuclear weapon and thus has no nuclear safety problem, thereby avoiding many problems associated with maintaining, handling, transporting, and guarding nuclear weapons.

B. Overview of Specific Studies

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that time, circa 1970, the nuclear-only INC did not meet with general political acceptance, but it did provide a springboard for the convertible INC. As then envisioned, a conventional warhead, preferably a precision-guided munition, could be simply and cheaply modified to give it a low-yield nuclear option.

2. Convertible Antiship Killer (CASK).[3]

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CASK warhead was proposed to greatly increase large ship kill probability when operated in the nuclear mode.

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(7) Personnel would not be exposed to radiation hazards as they are with present nuclear weapons aboard submarines.

(8) Perturbations to the DoD-developed warhead would be minimum, and the consequent reduction in kill radius for the conventional mode, depending on the design selected, would be no more than about 5%.

(9) The entire allowance of INCs could be safely secured in a properly designated vault or safe.

DOD The conventional _____ torpedo was in production when the study was conducted. This was a major disadvantage in considering a nuclear option. Incorporation of an INC option would probably have necessitated a redesign of the arming, fuzing, and firing (AF&F) circuitry, relocation of interior warhead components, and rework of the production facilities. This situation may have been the reason the Navy did not proceed with a convertible _____ DOD DOD torpedo. However, with the _____ torpedo being completely upgraded, the Navy may again examine convertibility. Hughes Aircraft is retrofitting the total Navy inventory of over 2000 Mk 48s.

4. Field Command, Defense Nuclear Agency (FCDNA) Insertable Nuclear Component (INC) Report.[5] This is the earliest source document that addresses various aspects of the then advanced nuclear-weapon design technology associated with the INC concept, both convertible and nuclear only. By this time the AEC had tested several INC design concepts at NTS and had completed several conceptual (Phase 1) studies _____ ACM, CASK, DOD DOD CADMUS, and _____ antiship missile).

This report discusses the effects of the convertible and nuclear-only INC concept on: (1) command and control, (2) custody and logistics, (3) operational readiness, (4) safety, (5) security, (6) administrative aspects of the four safety standards (DoD Directive 5030.15 of 10 June 1960), (7) relative costs, and (8) political ramifications.

5. Phase 2 Feasibility Study for Atomic Demolition Munitions (ADMs).[6]

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This led the DOE design laboratories to respond with a variety of design proposals that appeared feasible. The problems associated with integrating a nuclear option (convertible INC concept) into the warhead and circuitry of the Harpoon were addressed in subsequent studies.

Conclusions resulting from Phase 2 and Phase 2A studies included:[9,10]

- A nuclear-only replacement warhead compatible with the Harpoon weapon system is technically feasible and could be developed with little technical risk while satisfying modern nuclear weapons safety standards.
- [redacted] DOE b(3) DOD
- [redacted] DOD DOE b(3) Therefore, the performance characteristics, safety, and reliability of such a concept have not been fully evaluated. DOE b(3)
- Various containers (shipping, storage, destruct) for the INCs have been identified.

The Phase 2A study[10] covered cost, commonality, and additional technical issues from the Phase 2 and resulted in a study recommendation for a convertible [redacted] nuclear warhead with design considerations for future adaptation to the [redacted] antiship missile. DOD DOD The cost analysis concluded that: (1) excluding cost of special nuclear material, there is no significant cost difference between convertible and nuclear-only designs, and (2) a convertible warhead is more cost effective than a nuclear-only system in terms of operational flexibility. In summary, the convertible nuclear [redacted] DOD benefits clearly outweigh those of the baseline nuclear [redacted] The DOD commonality analysis concluded that a high commonality level could be

achievable for Navy low-yield warhead applications and would reduce Navy and DOE costs because of common weapon development and production. The two main technical issues were resolved by actual tests; that is, the convertible warhead survived in the conventional mode, and the Navy conventional HE (DESTEX) could be used in the convertible nuclear warhead. Phase 3 development engineering could be initiated immediately for either a nuclear-only or a convertible warhead for the [redacted] weapon system. The technical risks associated with developing either a nuclear-only or convertible warhead were judged low.

8. Convertible Concepts for the Mk 84.[11] The Air Force, with the participation of the DOE design laboratories conducted a study on the utility of giving the Mk 84 bomb a convertible INC option, especially when using the guided glide bomb (GGB) derivatives of the Mk 84: GBU-8, GBU-10, GBU-15 (V). The study included six proposals ranging from self-contained nuclear weapon add-ons to small capsule-type nuclear components. The designs were selected to illustrate the possibilities of the convertible INC concept and to show that application is highly system-dependent. Though several distinct benefits were identified, a formal requirement did not materialize.

"Convertible Concepts for the Mk 84" was the forerunner of a large and comprehensive study effort by the Directorate of Aerospace Studies entitled "A Utility Analysis of Convertible Nuclear Weapons."[12,13] The two study efforts overlapped to some degree but the Mk 84 study is narrower in scope. Much of the information furnished by the then ERDA laboratories for this effort was used in "A Utility Analysis of Convertible Nuclear Weapons."

9. A Utility Analysis of Convertible Nuclear Weapons.[12,13] This report investigated the operational feasibility of convertible nuclear weapons (CNWs) and analyzed their utility in comparison with standard nuclear weapons (SNWs). The concept was found feasible for lower-yield ranges. The CNWs also used new protective devices and storage facilities more effectively than SNWs because of their small size and the separability of the nuclear explosive package from the HE of the conventional weapon.

DOD 10. Nuclear Convertibility for the [redacted] --An Analysis.[14] The main conclusions of this FCDNA analysis provide one of the best condensed DOD overviews of convertible nuclear [redacted] advantages, including a matrix checklist of advantages and disadvantages. The general conclusion states: DOD "The total cost for the convertible nuclear [redacted] compared to the baseline

nuclear [redacted] is about equivalent. The convertible nuclear [redacted] benefits clearly outweigh those of baseline nuclear [redacted]."

11. Phase 1 Study for the GBU-15 Planar Wing Weapon (PWW).[15] This study examined the concept of equipping the GBU-15 Planar Wing Weapon (PWW) with a nuclear capability. The nuclear GBU-15 PWW would have great commonality with the conventional PWW. [redacted] One can see the possibility of a wide range of employment configurations for the GBU-15 PWW.

12. The Effectiveness of a Convertible Warhead. The effectiveness of a convertible warhead, when used in the conventional HE mode, compared with that of the original unmodified conventional warhead was addressed by Los Alamos in an outgoing telecommunication message to ATSD(AE) on August 1, 1977.

The blast effectiveness of a conventional HE warhead is proportional to the cube root of the mass of HE. When such a weapon is modified to make it convertible, its yield, and consequently its effectiveness, may or may not be reduced from that of the original unmodified warhead, depending on the convertible design used. [redacted]

It is possible to design INC convertible warheads that are fully equal in effectiveness to the unmodified conventional warhead. [redacted]

13. Insertable Nuclear Component (INC) Weapon Technology Applications Study.[16,17] The first part of this study examined all feasible current and

developmental U.S. tactical weapon systems, both nuclear and conventional, for use as INC systems. From all of these systems, six were selected as candidates for the second part which compared the cost and feasibility of using a convertible INC warhead with a mix of conventional and standard nuclear warheads. The six candidates chosen in Part 1 were: DOD tactical [redacted] sea-launched cruise missile (SLCM), CONDOR, [redacted] torpedo, advanced lightweight torpedo (ALWT), and standoff missile (SOM). Part 1 also identifies other weapons with significant operational advantages if deployed as convertible weapons.

Part 2 concludes that the INC weapon concept offers an attractive alternative for obtaining greater capability within a constrained budget. Additional savings are possible if the same INC can be shared among various convertible weapon systems (INC commonality).

14. Recent Work on Insertable Nuclear Component (INC) Warhead Designs.[18] This report summarizes the Los Alamos design and development work on INCs to the year 1977.

[redacted]

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[redacted]

Some concerns the report mentions are:

(1) [redacted]

(2) Existing ERDA classification rules affecting the nonnuclear portion of the warhead might need revision to accommodate the warhead when the INC is not in place.

(3) [redacted]

(4) Production plans for the weapon might need altering in order to accommodate INC needs.

(5) Cost studies of convertible warheads vs conventional HE/regular warheads and the cost of the SNM must be determined because cost is an important consideration in the overall evaluation of the weapon.

15. Implications for Theater Nuclear Forces of a Design Concept Using Separable Nuclear Components.[19] This study provides an initial but detailed qualitative assessment of a nuclear weapon design concept termed the "separable nuclear component (SNC) concept" and focuses on military rather than technical factors. Advantages and disadvantages of SNC weapons in comparison with standard sealed-pit nuclear weapons are analyzed, and their dependence on policy, posture, and weapon design factors is examined. The value of the SNC concept under four postulated theater nuclear force postures is analyzed. Potential applications of the SNC concept to delivery systems are considered and ranked as to potential merit. Political and other implications of introducing SNC weapons are discussed.

a. Conclusions. The study recommends that SNC weapon programs at the nuclear weapon laboratories should be reviewed to ensure that they are properly oriented and that factors such as military advantages, design feasibility, and costs are evaluated and constantly updated to allow for the latest developments in the field. The report suggests that DOE should continue conceptual design efforts on the SNC while emphasizing warheads for

[redacted]

theater-level ORA mobile missile systems and should try to get an SNC weapon where the RWC would not have a restrictive security classification. Further, the DoD should work closely with the DOE in evaluating the political-military utility of SNC weapons and in evaluating delivery systems which now appear to have high merit--specifically GLCM, MRBM, Pershing II and ADM.

16. Tactical Air-to-Surface Munition (TASM). The Air Force, with the assistance of the DOE laboratories, completed a pre-Phase 1 study of a nuclear air-to-surface SOM during 1976-1977.[20,21] A Phase 1 study was then conducted during the period of 1979-1980.[22] The results indicated substantial payoff when attacking mobile and fixed targets with an SOM as compared with nuclear gravity bombs. Though the study did not address INC systems, prelaunch survivability was a major concern with sealed-pit weaponry because of their constrained storage at main operating bases (MOBs). An INC weapon system may allow a large gain in survivability by deployment to numerous collocated operating bases (COBs) and alternate airstrips during crises.

17. Compendium of Convertible Technology.[23] This report is designed to provide an overview of the convertible concept by extracting from previous Navy studies the perceived advantages and disadvantages of the convertible concept. The [redacted] Phase 1, 2, and 2A studies are examined because they are the only studies that attempted to quantify the advantages and disadvantages; these studies also recommended that a convertible system proceed to Phase 3, development engineering. The conclusions of the [redacted] effort are reiterated and those conclusions that are system-independent are highlighted.

Table II-I, extracted from the report, provides a trade-off evaluation of convertible versus standard nuclear weapons. [redacted]

On the other hand, (1) convertible weapons are less costly taken overall than standard nuclear weapons, (2) designs can be modified so that

TABLE II-I

TRADE-OFF EVALUATIONS

Competing Characteristics	Choice	Rationale

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and reliability of the weapon after INC insertion in the field that need resolution.

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[redacted]

19. Advanced Intercontinental Ballistic Missile (AICBM). A weapon concept currently being investigated concerns small intercontinental ballistic missiles (ICBMs) deployed under different basing concepts. The primary concept is a road-mobile system, but air-mobile, air-transportable, and silo basing concepts are under consideration.

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[redacted] To increase survivability, the system could be deployed as a mobile system over a road network. Because of the proximity of the warhead to the missile propellant, significant safety concerns are raised when using standard sealed-pit warheads. Security concerns are of an equally severe magnitude because a full-up nuclear warhead is away from a fixed site.

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[redacted] Accidental nuclear detonation would be an impossibility unless the system was properly mated.

C. Summary of Service Requirements

In October 1977, the National Security Council (NSC), in reviewing the underground nuclear test program proposed by DOE/DoD, held approval of two tests in abeyance pending the DoD submission and interagency review of the military utility and arms control implications of INCs.

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[redacted] Several aspects of the NSC request proved so contentious within DoD that no response was provided.

Certain offices in the Office of the Secretary of Defense (OSD) objected

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to the Navy rationale for a nuclear [redacted] At that time, there was substantial opposition in OSD to any sea-based tactical nuclear weapons. Accordingly, the Navy suspended consideration of a nuclear

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capability [redacted] and DOE terminated active programs related to INCs pending resolution of the impasse between the DoD and the NSC over the

military utility study.[25] The DOE recently rescinded its freeze on testing of INCs and is allowing laboratory development to proceed.[26]

There is growing interest in the potential advantages of INCs within DoD and DOE, evidenced by the Army request for inclusion of INC warheads in the CSWS/JTACMS program. Another indication of interest in INC is the Chief of Naval Operation's (CNO's) memorandum stating the Navy policy to support further research and development of INC technology, to determine its full capabilities, and to consider incorporation of INC technology in development of new weapon systems.[27]

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[redacted]

During the same time frame, gun-assembled (GA) weapons were deployed. Figure III-2 shows a cutaway of the Mk 33 8-in. projectile, which is still deployed in large stockpile numbers. [redacted]

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[redacted]

C. Benefits of Early IFI and GA Weapons

The IFI weapon bodies were flown on alert and there were accidents that involved scatter of SNM. Without delving into details, the IFI designs prevented large-scale health hazards or loss of life because of the separation of the INC from the remainder of the bomb body. The results from an air crash involving an IFI weapon were: loss of life and aircraft, intact survival of

[redacted]

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the secondary (if there was one), and scattered uranium at barely detectable levels if an HE explosion or fire occurred. The nature of ionizing radiation allows one to conclude that if it is not detectable with modern instruments, then it is not hazardous to life. Uranium has very feeble radioactivity: 4.5×10^9 year half-life for ^{238}U and 0.71×10^9 year half-life for ^{235}U. In order to put into perspective the hazard of uranium scatter, we note that commercial airliners use depleted uranium as a counterweight material for control surfaces; a Boeing 747 uses about 500 lb of ^{238}U. Unfortunately, airliners crash and burn and sometimes scatter ^{238}U. Whether society is aware of it or not, it has accepted the (infinitesimal) peril of uranium scatter.

[redacted]

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[redacted]

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D. Disadvantages of Early IFI and GA Weapons

The IFI weapons were fielded with increasingly complex mechanisms for effecting in-flight insertion. During alert flights, the real bomb bodies were mated with the cores, and the Air Force literally wore them out. Many of the IFI bombs required a weapons officer in the bomb bay. As modern aircraft were developed, the presence of a man in the bomb bay became impossible.

The GA weapons were supplied with trainer weapon bodies as well as mock-up oralloy. The still-in-service W33 is assembled from the ground up in the field. A special truck with an officer and two specialists are required to

assemble an 8-in. weapon. Couple this with the need for a cordon of guards and one has an awkward logistical problem. A highly proficient team can assemble an 8-in. weapon in 45 min; then they handcarry the assembled weapon to the nearby 8-in. howitzer.

E. Sealed-Pit Technology

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The convenience of the all-up round without having to assemble the hardware is very attractive to the military.

The first sealed-pit weapons entered service in 1958, causing production of IFI weapons to cease. The safety crisis came in early 1966 with the accident at Palomares, Spain. A B-52 bomber on airborne alert collided with a KC-135 during a routine refueling operation. Four B28 weapons either fell out or were jettisoned from the falling bomber. One of the bombs fell into the Mediterranean Sea and was recovered relatively intact after about two months. Another soft-landed on the ground because the parachute deployed. The HE of one of the other B28s that hit the ground deflagrated, and the HE of the last one detonated. There was no nuclear excursion from either of the last two, but the plutonium was scattered around the area. Plutonium is pyrophoric, and if it is heated in the presence of air, it will burn and form an aerosol of plutonium oxide. Plutonium ingested through breathing or cuts is a very serious health hazard.

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Several acres of topsoil were scooped into barrels and buried at the Savannah River site in South Carolina.

About two years later in early 1968, another airborne-alert B-52 caught fire. The pilot dropped the crew by parachute and then rode the airplane down to a burning crash on an ice floe in North Star Bay, Greenland. The contaminated iceberg was cleaned up at greater cost than the contamination at Palomares. As a result of these accidents, the U.S. stopped flying alert bombers. Work to prevent future Palomares- and Thule-type accidents continues. One important result is the introduction of IHEs. [redacted] However, IHE is extremely insensitive and provides much greater safety. A modern, high-performance, nuclear weapon primary with IHE weighs considerably more than similar technology with the HMX-based explosive. Although many new tactical weapons (except the AFAPs) are being designed with IHE, there is no hint that alert bombers will take to the air with IHE bombs on a routine basis.

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The use of IHE and Cat F PAL (see Cat F PAL in Section F.1.a below) in modern weapons is increasing. These features undeniably increase safety but can result in decreased weapon effectiveness. That is, for a given weight, volume, or SNM usage, the yield may be less. The INC, or modular, weapon can fulfill safety requirements for reduced plutonium scatter without IHE and can protect the separate, vital weapon components without a Cat F PAL built into the weapon. For these reasons, the INC may be a more attractive alternative than the ever more complicated all-up weapon.

F. Current Concepts for Modular Weapons

1. Modern Weapon Systems Architecture. Essentially all nuclear weapons can be considered to be "insertable" in a sense. The B61 is a full-fuzing-option tactical bomb. [redacted] Another example of a weapon that could be considered insertable is the Pershing missile. It has a removable warhead section that is stored separately from the missile. The warhead will not function unless it is mated to the missile and properly launched. Or as a final insertable example, an

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AFAP will not operate unless it is properly fired from a howitzer. But while these systems are modular in this sense, they are not truly INCs according to the definition in Chapter I.

a. Cat F PAL. A new feature included in many modern nuclear weapons is the Cat F PAL. This is a feature built into the weapon to protect it from unauthorized use.

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b. Emergency Destructs (EDs). The DoD also has developed Standard Operating Procedures (SOPs) for emergency destructs.

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2. Recent Separable Component Concepts.

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a. Figure III-3 shows the convertible concept offered by Los Alamos for the

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With only a trivial reduction in HE

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Fig. III-3. Los Alamos Harpoon Proposal 3A warhead.

weight, the weapon body can be used in the conventional role.

[redacted]

The test device did not include INC attributes because the testing of INC weapons had been banned by Presidential Order in 1977.

[redacted]

c. Applejack. [redacted]

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[redacted]

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[redacted]

Fig. III-5. [redacted] DOE b(3)

[redacted]

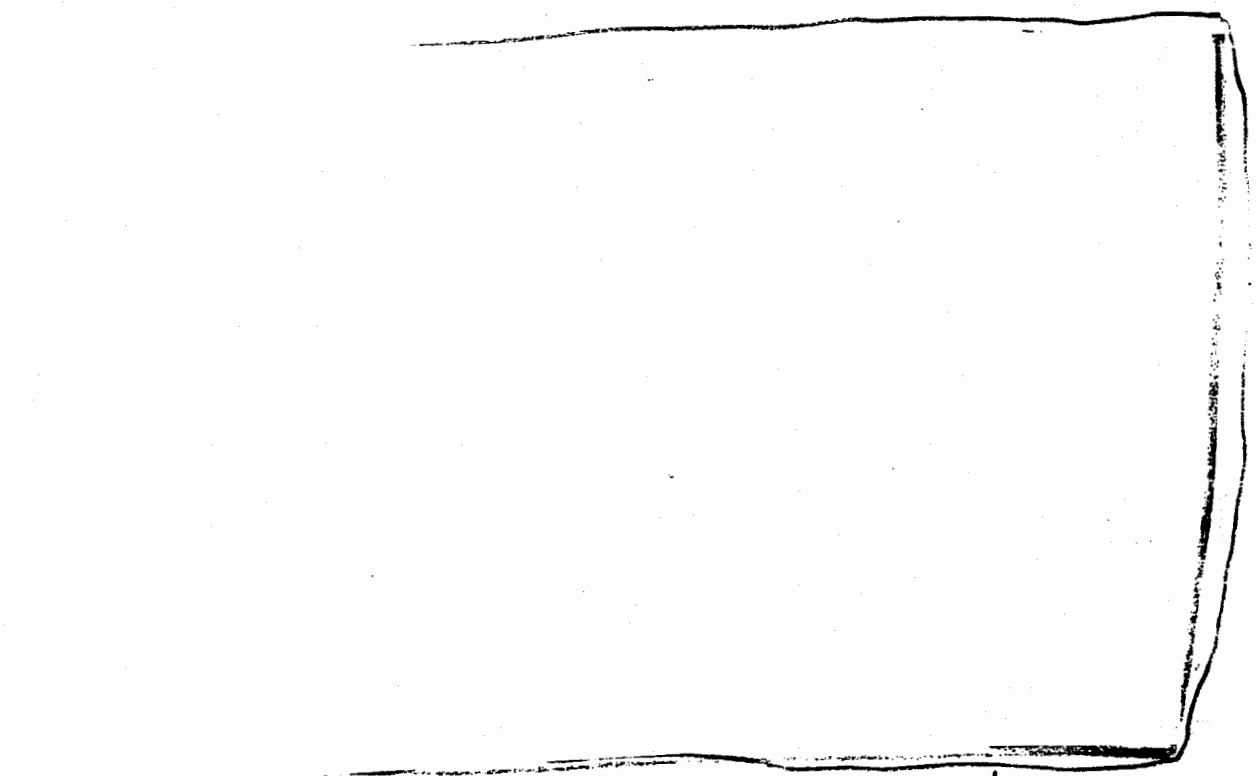


Fig. III-6. [redacted]

[redacted] Two problems associated with the concept are reliability and efficient use of SNM.

e. Two-Component Insertable Nuclear Component (INC). Figure III-7 shows the LLNL concept (Waxwing) for the CSWS/JTACMS. The concept involves a nondescript cavity in the warhead. First, the INC hardware package is installed; then the remaining volume is filled with paste HE. The objective is that the nondescript cavity will be unclassified.

[redacted] The road-mobile missile may eventually use HMX-based propellant, so HMX in the warhead might become acceptable, especially with the separation of the INC. [redacted]

G. INC/Convertible Warhead Observations

The IFI and GA weapons were of the era when the AEC developed weapons with less consideration for logistics or employment than is now possible, given their experience and knowledge. It is safe to say that the detailed concept

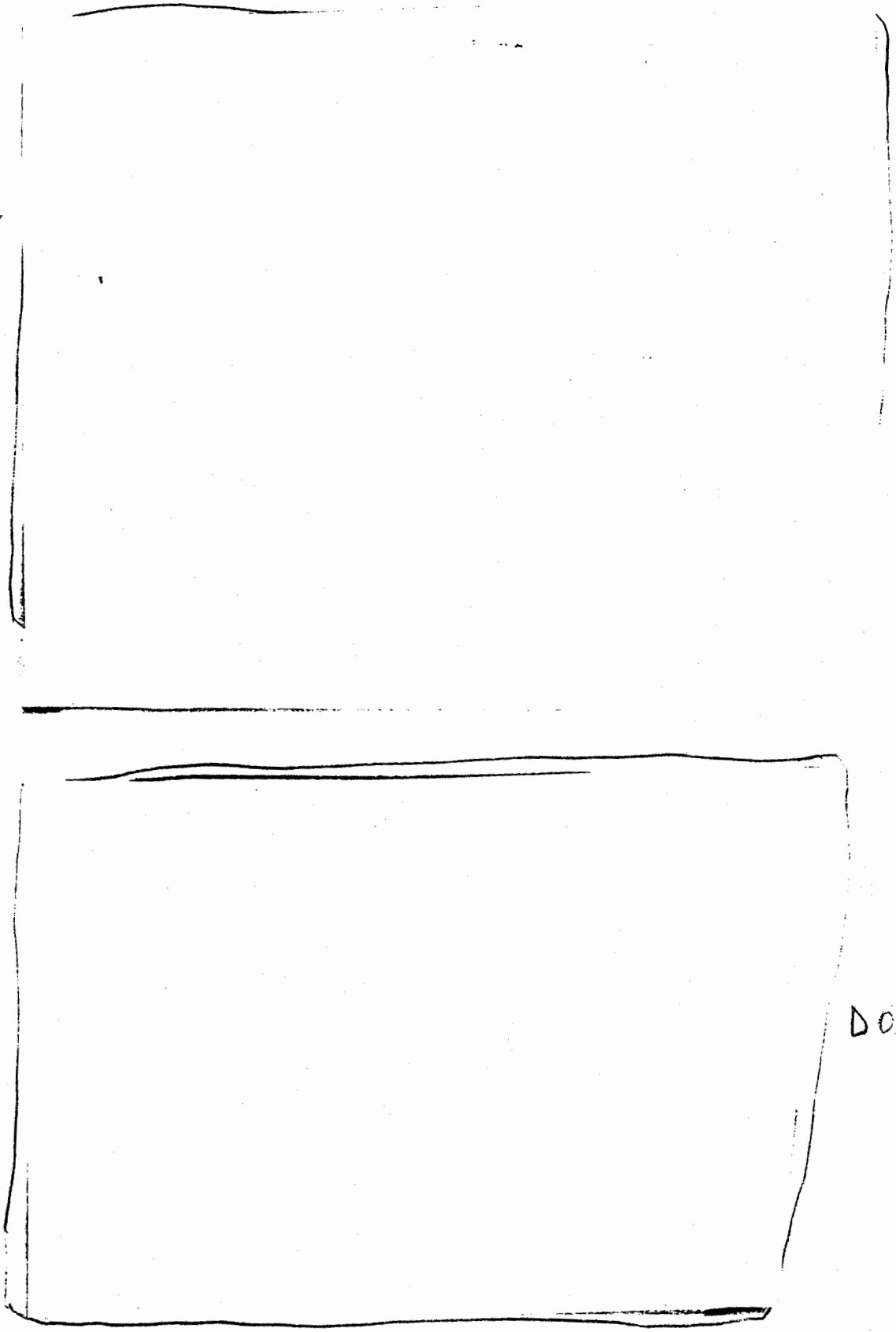


Fig. III-8. Los Alamos conceptual design for AICBM warhead.

formulation guidance was drafted to avoid problems that were evident during the presealed-pit era.

During the 1970's INC convertible warhead studies were done on [redacted] and [redacted] torpedoes, modular guided glide bomb (MGGB) with the Mk 84 2000-lb general-purpose (GP) bomb as the munition, [redacted]. Selective observations can be made concerning each of these INC efforts.

Unwritten nuclear weapon employment doctrine infers that only specified targets will be attacked. [redacted]

[redacted] The tritonal was cast into the "low-value" Mk 84 bombs with little concern for product uniformity but with great regard to cost. There were questions about whether a mill run Mk 84 bomb, modified for convertibility, would operate reliably.

The high-value (classified and expensive) weapons are protected much more carefully by the services than low-value weapons. The latter category includes rifles, cartons of Composition C, artillery ammunition, and GP bombs. Since high-value munitions are protected because of cost, classified components such as guidance, and the threat of misuse, it may be that adequate precautions are already in use to protect a convertible or INC.

CHAPTER IV

POTENTIAL APPLICATIONS OF MODULAR TECHNOLOGY

A. General

The objectives of modular technology are to increase the military utility of applicable weapon systems with minimum operational burden and cost to the user. These objectives are achieved through weapon design which is system dependent. Therefore, it was determined that the advantages and disadvantages of modular technology must be analyzed by comparing a set of weapon system/warhead characteristics with weapon categories that group "like" types of weapons into specific strategic and tactical categories.

It has been found in the past that evaluation of generic systems for adaptation of modular technology has not been successful because of the uinique character of each system. To minimize the impact of this problem, the weapon system/warhead characteristics and weapon categories where chosen so as to provide a reasonably definitive weapon "type" without actually selecting a system either deployed or in development.

B. Approach

A single matrix was developed for a generalized list of weapon categories and an assessment was made concerning the impact of modularity on the weapon system/warhead characteristics. The following assessment factors were used:

- Very positive impact
- Some positive impact
- No change
- Netgative impact
- Not applicable

For the assessment, certain assumptions were made and additional factors considered in determining the impact of modularity on systems within the weapon categories developed. The systems were evaluated on the basis of the STS of like-type systems currently deployed. From this evaluation, which is qualitative rather than quantitative, three of the most promising candidates were selected for a more detailed utility analysis.

1. Weapon Categories. The widely-used lists of strategic and tactical weapon systems were grouped into like types of weapons in specific strategic and tactical categories. This was done to develop a workable matrix and to more readily identify categories of systems that might benefit from modular technology. The weapon categories used in the assessment are as follows:

Strategic

Surface-to-Surface Reentry Vehicle

- Fixed
- Mobile

Air-to-Surface

- Bomb
- Cruise Missile

Air-to-Air-Missile

Strategic Antiballestic Missile

Tactical

Surface-to-Surface

- Projectile
- Reentry Vehicle
- Cruise Missile
- Short Range Missile

Air-to-Surface

- Bomb
- Cruise Missile

Antisubmarine Warfare

- Cruise Missile
- Torpedo

Surface-to-Air-Missile

Air-to-Air Missile

Atomic Demolition Munition

2. Weapon System/Warhead Characteristics. The advantages and disadvantages of modular warhead technology were analyzed for each weapon category by comparing their impact on 34 specific weapon system/warhead characteristics. These competing weapon system/warhead characteristics are intended to establish a broad set of measures encompassing a relatively complete range of attributes desirable for nuclear weapons. These weapon system/warhead characteristics, and their definitions, are as follows:

Command and Control (C^2). Those features that limit warhead/warhead section use only to authorized personnel during circumstances specifically designated by proper authority. Features such as PAL and nonviolent disablement are specifically included.

Convertible Weapon (Dual Capability). A type of INC weapon that has both a nuclear capability when the SNM is emplaced and a valid conventional or chemical capability when the SNM is removed. (The fact that an HE plug, specific submunition, or chemical agent must be emplaced in the cavity intended for the INC, to attain a valid conventional/chemical capability in some designs, does not eliminate those designs from the convertible weapon category.) (Technical Publication, TP 4-1)

Cost. Actual or potential expenditure of dollars and SNM required to develop, produce, and support a weapon capability throughout its life.

Design Impact. The impact of nuclear design on the weapon system when considering the following design requirements.

- Primary only
- Primary with boost

DOE 6(3) [redacted]

- Classification of WHB
- LLC considerations (the impact of modular technology on LLCs and changeout periods)

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Desired Yield Range. The capability of modular technology to provide the required yield range.

Destruct (Violent).

(TP 4-1)

Disablement Nonviolent. Nuclear weapons disablement which, through the destruction or disassociation of one or more key warhead or warhead section or atomic projectile components, temporarily destroys a weapon's ability to be used in its intended mode or as an ADM. (TP 4-1)

Economy of Nuclear Material. Judicious design of active materials and designated special weapons materials whose possession and use are licensed and controlled by the Nuclear Regulatory Commission (NRC).

Explosive Ordnance Disposal (EOD). Activities involved in render-safe procedures and the safe removal of explosive ordnance.

INC Weapon. A nuclear weapon design concept whereby a nuclear-capable warhead can be converted from a nuclear-inert warhead to a live nuclear warhead by inserting a nuclear component. There are two general subclasses of INC warheads--convertible and nuclear-only.

Intrinsic Radiation. Nuclear radiation intrinsic to a weapon and emitted through the weapon's outer surface.

Maintenance. The actions necessary to maintain material in the desired state of operational readiness throughout its life cycle. Maintenance functions include checkout, servicing, crew augmentation, replacement, modification, and depot maintenance. (U.S.A. TRADOC PAM 71-12)

Mobility. The capability of the system to be easily moved in an operational environment.

Operational Effectiveness (OPS Effect). The capability of a system to perform the missions for which it was designed.

Personnel and Training. The number of personnel required and skills necessary to operate, maintain, and support the material system in its operational environment throughout its life cycle. Training includes the identification of personnel skills, training devices and aids, instructions, training documentation, and manuals required to support a material system. (U.S.A. TRADOC PAM 71-12)

Range. The impact of modular technology on system range.

Regulations and Directives. Official DOE, DoD, and armed services publications that establish or implement policies or procedures governing all phases of the life cycle of a nuclear weapon.

Reliability. The probability (without reference to countermeasures) that a weapon will detonate when it has been delivered to its target. (TP 4-1)

Risk (Technical). The degree of probability that a technical goal will be achievable in the system considered.

Safety (Munitions). The prevention of the initiation of energetic materials by normal or abnormal inputs of energy when initiation is not desired. This should include nuclear, HE, and plutonium-scatter safety.

Security. A condition that results from the establishment of measures which protect designated information, personnel, systems, components, and equipment against hostile persons, acts, or influences. (JCS PUB 1)

Stockpile Life. The period of time a warhead is available for employment by DoD.

Stockpile-to-Target Sequence Environment. The aggregate of all external conditions and influences affecting the weapon throughout the STS, including transportation, maintenance, storage, and launch. Factors included are

temperature, humidity, and contaminants of the surrounding air; physical location and operating characteristics of the surrounding equipment and occupants; operational procedures such as acceleration, shock, vibration, heating effects, and radiation. (TP 4-1)

Support/Maintenance Facilities. Facilities to support the material system. Examples are: physical plant, real estate, portable buildings, concrete pads, revetments, roads, runways, housing, shops, depots, test sites, computers, training facilities, and storage areas.

Survivability. The capability of a system to withstand a manmade hostile environment without suffering abortive impairment of its ability to accomplish its designated mission. (TP 4-1)

Testing. The procedures and equipment required of DoD personnel (at any level) to certify the reliability of the system, or any of its components, in contrast with the more "conventional" nuclear system.

Transportation and Handling. The procedures, equipment, materials, and facilities needed for packing and crating; the use of reusable containers; supplies necessary to support packaging, preservation, storage handling, and/or transportation of prime equipment; support and test equipment needed; repair parts and supply support; personnel; technical data; publications; and facilities. (U.S.A. TRADOC PAM 71-12)

Vulnerability. The characteristics of a system that cause it to suffer a definite degradation as a result of having been subjected to a certain level of effects in an unnatural (manmade) hostile environment. (TP 4-1)

3. Assumptions and Additional Considerations. In development and assessment of the matrix of potential modular applications, certain assumptions and considerations were applied.

(1) Evaluations were made on the basis of providing something better with modular technology than currently exists in a standard nuclear warhead design.

(2) Certain warhead characteristics were weighed more heavily than others in this assessment. These were

design impact

operational effectiveness

safety

security

survivability

transportation and handling

(3) It was assumed that modular design technology would use relatively higher amounts of SNM; therefore, economy of SNM would reflect a "negative" in most generic system considerations.

(4) Generally, a reduction in reliability can be expected in most modular technology designs and was so reflected for all generic system categories.

(5) Deployment of modular systems would necessitate a restructuring of current regulations and directives addressing nuclear weapon storage, transportation, and handling, and therefore reflect a negative impact.

C. Assessment

1. General. Evaluation of the matrix found in Fig. IV-1 indicates that the strongest contenders for modular technology are tactical systems. Those tactical systems that appear to be the most favorable modular candidates but still allow adaptation to other tactical uses include the following:

(1) Land-launched tactical missile/cruise missile (SSM/SAM), either convertible or nuclear-only

(2) Sea-launched tactical missile/cruise missile (SSM), again either convertible or nuclear-only

(3) Air-launched tactical bomb or air-to-surface missile with a nuclear-only capability

These three candidates can cover a wide variation of STS environments and system variations. Other systems identified for future consideration in modular technology applications include the strategic mobile missile system (AICBM), an air-to-air missile (for strategic or tactical use), and several tactical-only systems.

2. Specific Assessment Considerations. A number of observations can be made in reviewing the matrix and resulting evaluation.

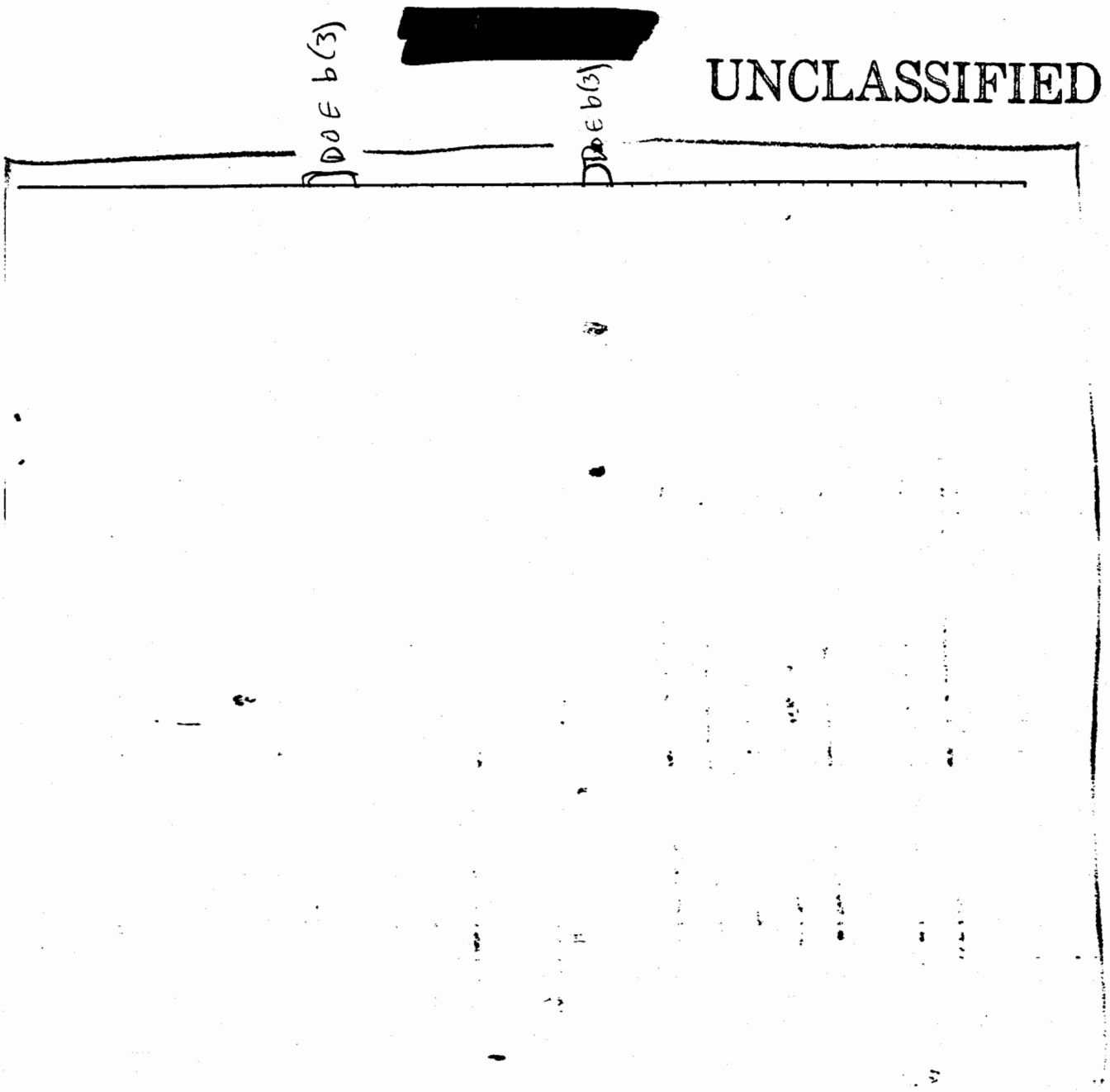


Fig. IV-1. Assessment matrix.

(1) Certain characteristics reflect strong support for modularity technology in all weapon categories. These include

destruct (violent)

disable (nonviolent)

explosive ordnance disposal (EOD)

These three categories encompass security measures designed to ensure against theft or unauthorized use of nuclear weapons. By separation of components, the modular concept provides inherent improvement in security during peacetime and in crisis against the threat of theft

or unintended use. Standard nuclear weapons are not generally amenable to such methods of use denial except through design and operational measures that are relatively cumbersome in comparison to component separation.

(2) Those tactical systems that appeared to be the most favorable candiates for application of modular technology reflecting strong support in the following additional warhead characteristic categories.

command and control

yield range

mobility

safety

security

small volume/lightweight

stockpile-to-target sequence environment

support/maintenance facilities

survivability

transportation and handling

vulnerability

design impact (primary and boost)

(3) [redacted]

DOE b(3)

DOE b(3)

DOD

(4) Some tactical candidates scored very well but were not selected.

DOD

Projectile. [redacted] it was considered improbable that a new projectile would be considered for development in the near term.

Torpedo. A new nuclear torpedo has been under development consideration for several years but is still in question. There is a good possibility that modular technology would have application for

the selected candidate systems, either a new torpedo or in retrofit of [redacted] torpedoes.

Atomic Demolition Munition. The development of a new ADM is questionable at this time. [redacted]

Air-to-Air Missile. The requirement here could have Air Force and Navy applications but does not appear to have the urgency that the selected candidates reflect in meeting projected DoD needs. This would be a good follow-on candidate for modularity consideration.

(5) Within the strategic categories, the mobile ICBM [surface-to-surface reentry vehicle (RV)] appeared to be a reasonable candidate for modularity, but in view of the political and operational problems associated with mobile strategic systems in the CONUS at this time, it was viewed as another good follow-on candidate.

CHAPTER V

UTILITY ANALYSIS

A. Introduction

This chapter examines the utility of modular nuclear warheads within the context of three generic candidates, one system for each of the military services. What we have attempted to do is address the advantages and disadvantages offered by these kinds of warheads. We recognize that hardware is only one aspect of the military equation; the conclusions we reach here must be tempered by the existing political and military doctrinal environment and especially by the current administrative framework. Many factors, including the element of political and military strategy, leadership, personnel training, application of the principles of war, and modus operandi of the STS, are major parameters that ultimately drive the real worth of these systems whether in peacetime deterrence or wartime application. Admittedly, the focus is within the European environment where the survivability of our nuclear forces has been and continues to be severely questioned. We see that modular nuclear weapons potentially offer a substantial increase in survivability, particularly for the Army and Air Force candidates. But turning away from our potentially most important war area to those areas of the world where wars may be more likely, a force of Army or Navy convertible systems offers tremendous flexibility to respond conventionally and to deter nuclear responses within special theaters. Several advantages, including the all-important increase in survivability, also accrue to the Air Force candidate modular system that is dedicated to the nuclear role.

Let no one doubt that obstacles must be overcome to field successfully these kinds of warheads. The technical challenges, however, are not high risk. Reliable and safe modular warheads can be built using present design and engineering capabilities. It is their impact upon the well-established administrative, security, and surety community that involves major ramifications. If modular systems are treated as "business as usual," then only safety advantages result from the separation of plutonium from the HE during most of a warhead's life. Instead, the logistic and regulatory community should modify the peacetime logistic system in order to realize a survivable nuclear system, even with the probability of an increase in costs. Increases in survivability should be

the primary reason for developing, producing, and deploying modular nuclear warheads. Though the benefits of having safer warheads are of great importance, we realize that modern standard warheads have an unblemished safety record regarding accidental nuclear detonation;

DOD

The real benefits in safety improvements lie in allowing changes in the transportation and storage of nuclear weapons that, in turn allow greater dispersion and enhanced survivability. Personnel training needs high emphasis, not only in the obvious mechanics of inserting the nuclear component into the WHB or in installing additional submunitions in a field environment, but also in the total tactics of moving from unit kasern to field locations, or in deploying to collocated Air Force bases, or in changing missile capabilities afloat, as the service case may be.

Beyond the scope of this analysis are several important areas that will have an impact on modular warhead deployments. We do not examine the arms control ramifications which are always of concern to military planners when trying to field new hardware. We also do not examine the strategic and tactical doctrine under which the Armed Forces operate. Both of these factors can affect the ultimate utility of modular weapon systems. In this utility analysis, we assume away the arms control problem and accept the major tenets of the present doctrinal framework (such as flexible response) in applying our logic. We do modify some of the underlying tenets to exploit the utility of modular weapons.

Other political and military considerations, more microscopic in nature, do require treatment. In this analysis, we treat these considerations under a generally favorable environment in order to determine the advantages and disadvantages of modular systems.

We initially describe the generic weapon systems, then take the characteristics used in Chapter IV to identify potential modular applications and examine them through a taxonomical structure consisting of sections on safety, security, survivability, operational effectiveness, logistics, and costs. Relative utility numbers are generated for each section and then aggregated to try to quantify the advantages and disadvantages; the reader can accept or reject this tool yet still support the findings in the summary section which ends the chapter. The conclusions and recommendations that emerge from this utility analysis are given in Chapter VII.

B. Weapon Description and Stockpile-to-Launch Sequence (SLS) Differences

1. General. The approach of this section is to describe initially the candidate modular warheads, then to describe the three modular weapon candidates, and finally to compare their SLSs with the baseline systems. All three candidates are low-quantity buy, high-value munitions.

2. Candidate Modular Warheads. Two warhead candidates are chosen to satisfy potential tactical yield requirements. We vastly prefer the first candidate because of its smaller size, lower weight, and simple design.

a. Warhead Candidates #1. [redacted] The second component is the WHB. For the nuclear application, [redacted] Convertible weapons would also contain additional volume in the WHB for conventional munitions, either sub or unitary. Further investigations in the areas of costs, range, safety, and reliability are needed to determine if a conventional HE filler plug for the cavity in the WHB is warranted for conventional missions and if the conventional munitions normally in the WHB should be removed before firing a nuclear mission. The WHB body would not contain RD. [redacted]

[redacted] The INC would contain the nuclear materials, primary, secondary, IHE, and warhead electrical system. Its main disadvantage is in the large size and heavy weight of the INC. [redacted]

c. Discussion. These modular warhead designs present some technical development and production difficulties, especially in trying to ensure that the WHB contains no RD. Some low risks face the warhead designers. The biggest challenge is to design and produce a highly reliable system that must undergo field insertion. Probably the major challenge is the successful interconnect of the WHD electrical system with the missile fuzing system. Of course present day Lance and Pershing warheads are field mated to their missiles and they possess high relability. Nevertheless, the INC must undergo, in the field, an operation--the mating of explosives and the pit--that is normally done at a DOE plant. Though reliability may be less, designers are confident of providing a highly reliable system by using proper technology and assuming suitable user training in adverse environments, such as sandy southwest Asia or cold and damp northwest Asia.

3. Army Requirements. The Army missions for the analysis are

- Conventional fires to [redacted] primarily by using submunitions (and perhaps a chemical round) against armored and other tactical vehicles
- Nuclear fires to do the same mission
- Conventional air-defense at medium to high altitude, possibly tactical nuclear ABM defense, and back-up SSM nuclear fires

Current baseline systems are the Lance with conventional warhead for the first mission, the [redacted] nuclear warhead for the second, and the Improved Hawk and Hercules for parts of the last mission. The Lance suffers from several shortcomings: it is manpower inefficient, range-limited, old and increasingly difficult to maintain, and relatively inaccurate and unresponsive because of its time-consuming warhead mating operation. The Improved Hawk, though still one of the best medium-range air-defense systems in the world, is being replaced by the Patriot. The Patriot will also replace the very old Nike-Hercules. The Hawk and the Patriot are not fielded with a nuclear capability.

The AD batteries would generally use a unitary conventional warhead, but these units would also possess a number of missiles that could deliver back-up surface-to-surface nuclear and/or tactical nuclear antiballistic missile (ABM) fires. The field artillery would be dedicated to the ground role, with the capability to deliver nuclear warheads or conventional submunitions (and possibly chemicals). Whether or not these missiles should be convertible in the AD role (unitary conventional or nuclear) and convertible in the field artillery (FA) role (submunition or nuclear) depends upon cost and operational effectiveness trade-offs. We propose a dual-capable missile, however, for two reasons: (1) the greater economics from developing and producing the missile in a joint program and (2) increased survivability through deployment of back-up INCs and SSM missiles to AD units.

Figure V-1 shows the SLSs in peacetime. Fig. V-2 shows these sequences in alert or during wartime.

What are the major differences between the baseline systems and the modular candidate within their SLSs? Table V-I succinctly shows the main differences.

Baseline Lance

DOD

Modular convertible SSM/SAM

DOD

Fig. V-1. SLS of Army systems (peacetime).

Baseline Lance
(wartime)

DOD

Modular convertible SSM/SAM
(alert/wartime)

E/L

Fig. V-2. SLS of Army systems (wartime).

DOD

4. Navy Requirements. The Navy missions are:

- Conventional fires against ships, submarines, and shore installations
- Nuclear fires against the above

The current baseline system is the a conventional system that can be launched from submarines, airplanes, and ships.

The Phase II and IIA studies presented several design approaches with this yield. A number of conventional could be produced with DESTEX, leaving a cavity for insertion of an INC (nuclear application) or a filler component of additional DESTEX (conventional application). Existing ship-board launchers would be used and modified to allow rapid change-out of INCs and conventional filler plugs. A safe secure container would be built and stored away from the crew to For comparative stockpile-to-launch purposes, we configure an expanded baseline consisting of conventional and dedicated standard nuclear Figure V-3 graphically presents the SLS of the Navy system. Table V-II then depicts the differences between the mixed force of Harpoons and a modular convertible force.

5. Air Force Requirements. The Air Force has identified a tactical mission of with nuclear munitions. The Army and Air Force are currently staffing joint interdiction procedures.

[redacted]

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TABLE V-II

COMPARISON OF NAVY BASELINE AND MODULAR CANDIDATES

	Procedure	Baseline Conventional Plus Dedicated Nuclear Harpoon	Convertible Harpoon
1.	Production	All-up canisterized conventional weapon All-up canisterized nuclear weapon	Force of canisterized missiles with HE (WHB) and emplaced conventional plus
2.	Warhead Transportation and Storage	On missile within canister (conventional and nuclear)	Conventional warhead on missile within canister. INC transported and stored in secure storage container away from canisterized missile and shielded away from crew
3.	Missile Storage	Conventional: In canisters with warheads at storage areas or in ship magazines/launchers Nuclear: In special storage areas or in special ship magazines	Missile stored as conventional Harpoon is today
4.	Peacetime Dispersal of WR Warheads	Full-up warheads on missiles in magazines afloat or in special storage	INCs (away from missiles) are in magazines afloat or in special storage areas
5.	Wartime Dispersal of WR Warheads	Onto launchers	Onto launchers; INC inserted into missile
6.	PAL Unlock	Upon message receipt and authentication	Same

An INC TASM could provide a means of increasing weapon survivability if operational procedures and security regulations can be modified (Fig. V-4). An INC separate from the WHB, though still an RD item, is not a nuclear weapon. By dispersing the WHB (less INC) to separate locations in peacetime and storing the INC and its containers in underground storage vaults/wells at both MOBs and COBs, the enemy targeting requirements have risen greatly. Crisis conditions may see the flushing of INCs and exportable shelters to some of the 600 plus airstrips in Europe that can handle F-111 or smaller fighters as ea

[redacted]

Baseline Gravity Bomb

DOD

Modular TASM

DOD

Fig. V-4. SLS of Air Force systems.

DCD

C. Approach

The summary section at the end of this chapter lists the major advantages, disadvantages, and unknowns that are associated with S^3, operational effectiveness, logistics, and costs.

TABLE V-III

COMPARISON OF AIR FORCE BASELINE AND MODULAR CANDIDATES

We have stressed the importance of a favorable regulatory and administrative environment upon the potential utility of the modular candidates. Except for the case of safety where modular weapons are inherently more safe than standard nuclear weapons, a favorable environment is necessary to realize fully the advantages of modular weapons and to minimize the potential disadvantages. Environment is used here in the broadest sense of the word and includes major external factors--political, economic, technical, administrative, or military--that may have an impact upon the three modular candidates.

Combining the advantages and disadvantages intuitively into a decision to proceed or not to proceed with development and engineering is difficult. We provide a simple scheme for aggregating the advantages/disadvantages into an overall quantitative merit value. We then use this scheme to present our quantitative numbers as a guide (see tables at the end of each subsection). The steps in the scheme are:

(1) Assign a number from zero to three based upon relative evaluation of the value/importance (VI) of each subarea and major area.

- 0: Unimportant
- 1: Some importance
- 2: Very important
- 3: Extremely important

(2) Evaluate the utility/worth (U) of the modular warhead as compared to that of the the baseline system in meeting the subarea's requirements.

- -1.0: Much inferior to baseline
- -0.5: Inferior to baseline
- 0: Same as baseline
- +0.1: Insignificantly better than baseline
- +0.2: Slightly better than baseline
- +0.4: Somewhat better than baseline
- +0.5: Better than baseline
- +0.7: Substantially better than baseline
- +1.0: Much better than baseline

(3) As a conclusion to each major area (for example Safety) discussion, calculate the average merit for all subareas (N in quantity) within that major area.

(4) Repeat step 3, above, to aggregate all major areas into a final worth.

$$\frac{\sum_{i=1}^{N} \left(VI_i \times U_i\right)}{\sum_{i=1}^{N} VI_i}$$

D. Safety

Safety is the prevention of the initiation of energetic materials by normal or abnormal inputs of energy when initiation is not desired. We distinguish between two types of safety: (1) nuclear detonation safety where an inadvertent detonation gives a nuclear yield in excess of four pounds HE equivalent and (2) plutonium-scatter safety where detonation of the HE results in dispersion of plutonium. Even in an unfavorable regulatory and administrative environment, modular warheads engender increased safety levels.

1. Nuclear Detonation

a. Statement

Separation of explosives from nuclear material inherently increases nuclear detonation safety. (All three candidates)

- Before insertion, modular warheads are safer than the baseline nuclear warheads.
- After insertion, modular warheads are as safe as baseline nuclear warheads.

b. Discussion

Modern nuclear weapons are safe from accidental nuclear detonation, especially those containing IHEs--the U.S. has a perfect record. However, modular warheads are safer before insertion because the INC is physically separated from the HE. The probability of an accidental nuclear yield is zero. After the INC is inserted into the WHB, the modular warhead candidates are as safe as the baseline warheads and can meet the stringent military requirements. INCs would incorporate modern safety features such as weak-link/strong-link circuits and would be stored in safe secure containers. The Army and Air Force candidates would use IHE; the Navy would use DESTEX for their convertible system.

As an example for the first merit estimation and to indicate our logic, we rate the VI of nuclear detonation safety as 3 (extremely important). Compared

to the baseline systems which already afford high nuclear detonation safety, we assign a U of +0.2 (slightly better than baseline).

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	3	+0.2	+0.6

2. Plutonium-Dispersal

a. Statement

Accidents involve lower probabilities of plutonium dispersal. (All three candidates)

b. Discussion.

The two accidents at Thule, Greenland; and Palomares, Spain, in the 1960's required significant cleanup operations and caused much greater political results (such as changes to B-52 alert operations). Future accidents that cause plutonium scatter, especially if in populated areas, could create tremendous problems. The use of IHE for some of our stockpiled weapons has greatly reduced some of these concerns. Nevertheless, the sheer number of nuclear weapon movements leaves the door open for future plutonium dispersal accidents. An accident involving the movement of a WHB (less INC) would not disperse plutonium (it has none) nor should it be called a nuclear weapon accident or incident. An accident involving an INC would have a much lower probability of plutonium dispersal because of substantially reduced HEs. This is because the IHE used in the INC is minimal. Also, the secure container could generally be stronger than the shipping containers and canisters of the baseline systems, meaning less chance for rupture.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	3	+0.4	+1.2

3. Intrinsic Radiation

a. Statement

Intrinsic radiation concerns can be lessened by storing INCs in shielded containers. (Navy)

Intrinsic radiation concerns are increased because of greater amounts of nuclear materials in the INCs if shielding is not adequate. (Navy)

b. Discussion

The proximity between crew living and working quarters aboard Navy ships and particularly submarines is a real health concern. In some cases aboard submarines, the crews "live" on top of the nuclear weapons. Intrinsic radiation from nuclear warheads might subject crews to levels above that permitted by medical regulations. An all-up nuclear canistered Harpoon is not easily shielded or stored away from crews; a small INC is. Already shielded by its container, additional shielding can be easily provided to the INC because of its small volume. The second concern deals with exposures when handling the INC out of its container. The time intervals are so short that the radiation effect is minimal. Finally, intrinsic radiation concerns are of much smaller magnitude in the Army and Air Force considerations because of personnel separation from the nuclear munition.

c. Merit Estimation

Candidate	VI	U	VI x U
N	2	+1	+2
A, AF	0	+1	0

4. Total and Average Merit Under Safety.

Candidate	Total Merit	Average Merit
A	+1.8	+0.3 (somewhat better than baseline)
N	+3.8	+0.5 (better than baseline)
AF	+1.8	+0.3 (somewhat better than baseline)

E. Security

We define security as a condition that results from the establishment of measures to protect designated information, personnel, systems, components, and equipment against hostile persons, acts, or influences. Several technical and operational advantages accrue to modular warheads.

1. Command and Control

a. Statement

Command and control requirements are now on components that are individually unable to produce a nuclear yield. (All three candidates)

b. Discussion

Command and control is defined as those features that limit warhead use only to authorized personnel during circumstances specifically designated by

proper authority. Baseline systems are protected by PALs and are stored in special nuclear storage areas. One of the reasons for this is the fact that the baseline nuclear round is a full-up nuclear round. An INC in its secure storage container (with PAL, etc.) and the WHB are not full-up rounds by themselves.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	2	+0.7	+1.4

2. Nonviolent Disablement

a. Statement

Nonviolent disablement measures are more compatible with a secure container than a full-up munition or missile. (All three candidates)

b. Discussion

[redacted]

DOD

DOE b(3)

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	1	+0.2	+0.2

3. Emergency Destruct

a. Statement

Emergency destruct of nuclear capability and design information is more readily conducted within the secure container. (All three candidates)

b. Discussion

DOE

[redacted] the greater quantities of HE make the probability of plutonium dispersal greater than zero. However, design information may still be inferred. The modular candidates would have their INCs stored in a command-destruct secure container. It would be so designed as to contain the destruction of the INC, maintain its integrity, and yet eliminate design information.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	2	+0.7	+1.4

4. Safe Secure Container

a. Statement

The safe secure container is virtually secure and reduces concerns for HE protection. (All three candidates)

b. Discussion

DOE b(3)

[redacted]

DOE b(3)

[redacted]

ICL

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	1	+1	+1

5. Vulnerability to Theft

a. Statement

DOE b(3)

[redacted]

DCI

b. Discussion

The INC within its container, while not portable by a single man, is certainly easier to move than a missile, W81 or W70 warhead, or B57 or B61 bomb. This particularly may apply to the Army candidate and to a lesser extent the Air Force and the Navy candidates, according to the number of sites and potential exposure to security threats.

DOE (b)(3)

[redacted]

This may do wonders for security but it has a negative impact upon operational effectiveness and survivability.

c. Merit Estimation

Candidate	VI	U	VI x U
A	2	-0.4	-0.8
N	1	-0.2	-0.2
AF	2	-0.4	-0.8

6. Peacetime Dispersal

a. Statement

Peacetime dispersal to using units (Army) or deployment during crises/hostilities to collocated air bases or strips (Air Force) for increased survivability means:

- Exposure to more personnel
- Storage at less secure areas than the baseline unless storage wells or exportable shelters are provided

b. Discussion

By personnel, we mean authorized and unauthorized military plus civilians.

Dal

Storage aboard Navy ships and submarines would also be modified to account for shielding of the INC containers and storage away from the crew. The negative impact of dispersal upon Naval security should be very small.

c. Merit Estimation

Candidate	VI	U	VI x U
A	2	-0.4	-0.8
AF	2	-0.4	-0.8
N	1	-0.1	-0.1

7. Total and Average Merit Under Security

Candidate	Total Merit	Average Merit
A	+2.4	+0.2 (slightly better than baseline)
N	+3.7	+0.5 (better than baseline)
AF	+2.4	+0.2 (slightly better than baseline)

F. Survivability

DOD

1. Enemy Targeting

a. Statement

DOD

b. Discussion

DOD

DOD

[redacted]

[redacted]

c. Merit Estimation

Candidate	VI	U	VI x U
A	3	+1	+3
AF	3	+1	+3
N	3	+0.1	+0.3

2. Nuclear Signature

a. Statement

[redacted]

b. Discussion

[redacted]

We do not see differences for the modular Navy system.

c. Merit Estimation

Candidate	VI	U	VI x U
A, AF	3	+1	+3
N	1	0	0

3. Deployability

a. Statement

INCs can be rapidly deployed to alternate locations during wartime. (All three candidates)

b. Discussion

c. Merit Estimation

Candidate	VI	U	VI x U
A	2	+0.5	+1.0
AF	2	+0.5	+1.0
N	1	+0.2	+0.2

4. Concealability

a. Statement

INCs are less visible and more easily concealed. (Army, Air Force)

6. Insertion Times

a. Statement

Insertion of the INC into the warhead body requires time. (All three candidates)

b. Discussion

DOD

c. Merit Estimation

Candidate	VI	U	VI x U
N, AF	1	-0.4	-0.4
A	1	-1.0	-1.0

7. Total and Average Merit Under Survivability

Candidate	Total Merit	Average Merit
A	+8.0	+0.6 (substantially better than baseline)
N	+1.1	+0.1 (insignificantly better than baseline)
AF	+7.6	+0.6 (substantially better than baseline)

G. Operational Effectiveness

Broadly defined, operational effectiveness means the capability of a system to perform the missions or functions for which it is designed. This definition could then include survivability and security. To limit the scope, we narrow operational effectiveness to include mobility, targeting flexibility, enduring capability, storage flexibility, nuclear yield, conventional warhead effects, reliability, range, and foreign political acceptability. The three candidates generally offer improvements over the baseline systems in this area.

1. Mobility

a. Statement

Strategic and tactical mobility for European and special theaters are increased because of the small size and weight of INCs and lack of nuclear materials in the WHB. (All three candidates)

b. Discussion

The baseline nuclear weapons constrain the defense transportation system in its ability to move the weapons rapidly in large numbers. Part of the reason is physical: The baseline nuclear warheads are larger, weigh more than the INCs, and contain significant amounts of SNM next to a large amount of HE. The other part is political: The baseline warheads are full-up nuclear rounds. For example:

(1) Strategic mobility suffers because

- [redacted]
- [redacted]

(2) Tactical mobility also suffers because

- [redacted]
- [redacted]

At the risk of overt repetition, [redacted]

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	3	+1	+3

2. Targeting Flexibility

a. Statement

[redacted]

b. Discussion

c. Merit Estimation

Candidate	VI	U	VI x U
A	2	+0.5	+1
N	3	+1.0	+3
AF	1	0	0 (not convertible)

3. Enduring Capability

a. Statement

Enduring capability is available through the rapid logistical resupply of INCs. (All three candidates)

b. Discussion

DOD

surviving missiles and WHBs than the resupply of a full-up nuclear warhead and missile.

The advantages to the Air Force dedicated TASM are not as large. The number of missiles and WHBs will equal the number of INCs as this is not a convertible candidate. Nevertheless, loss of an INC without concomitant loss of WHBs and missiles will make resupply of INCs stockpiled out of theater easier than resupply of a full-up baseline gravity bomb.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N	2	+0.7	+1.4
AF	2	+0.4	+0.8

4. Storage Flexibility

a. Statement

Convertible weapons allow full nuclear or conventional capabilities where storage areas are limited. (Navy)

b. Discussion

c. Merit Estimation

Candidate	VI	U	VI x U
N	3	+1	+3
A, AF	0	0	0

5. Nuclear Yield

a. Statement

b. Discussion

Secondary missions for the Army SSM and Air Force TASM modular candidates might require destruction of relatively hard fixed targets. This more probably would be the case for the Air Force in its interdiction mission. If these fixed-target requirements are imposed, and other nuclear systems (B61 gravity bomb, GLCM, Pershing IA or II) are not deemed sufficient to cover this target set, then we would strongly recommend the development of a terminal correlation module to be used by some of the SSMs and/or TASMs to get CEPs down to about 30 meters.

DOE bC

[redacted]

DOE bC

DOD

[redacted] It would be heavy, cumbersome, and difficult to handle. Many of the advantages that we discussed earlier would erode or disappear. To minimize the impact, assign the mission to only one of the services, say the Air Force, and assign only a part of the TASM force (and use a full-up nuclear munition instead of a modular one). Keep the remaining TASM force modular with one-stage INCs.

DOD bC

The merit numbers below assume that the Air Force is assigned the additional fixed-target mission and either builds only part of the TASM force with INCs (the rest are two-stage standard TASMs) or builds additional GLCMs and/or B61s. The yields of the Army candidate would then be sufficient.

c. Merit Estimation

Candidate	VI	U	VI x U
AF	3	-0.5	-1.5
A,N	3	0	0

[redacted]

6. Conventional Warhead Effects

a. Statement

Convertible weapons may incur reduced conventional effectiveness because of WHB body volume devoted to the nuclear application. (Army, Navy)

b. Discussion

LCL

DOE b(3)

[redacted] A conventional filler plug could be developed, but this would require careful study of the trade-offs between increased effectiveness versus the logistic effect of another component upon the STSs.

The Army's problem is more serious with regard to its conventional SSM role (no major implications are seen in the SAM role which uses a unitary HE warhead). This mission of conventionally stopping the enemy second-echelon forces requires the use of submunitions. [redacted]

DOD

[redacted] This volume is lost to submunitions and may make the convertible SSM ineffective and too costly. If so, the dual-purpose SSM/SAM should still receive consideration for AD batteries, although the field artillery batteries would then have both full-up conventional SSMs and dedicated modular nuclear SSMs.

c. Merit Estimation

Candidate	VI	U	VI x U
N	2	-0.1	-0.2
A	2	-0.5	-1.0
AF	0	0	0

7. Reliability

a. Statement

A reliability degradation is expected. This can be minimal with the use of high production standards, affordable because of the small weapon system buys, and fully acceptable, especially in insertion operations within a clean environment. (All three candidates)

b. Discussion

DOD

[redacted]

DOE 1.0. |

The convertible warheads, when used conventionally, intuitively should have reliabilities almost identical to the conventional baseline systems. This is normally driven by the reliability of the missile. The cavity within the WHB itself can be designed to have a negligible reliability effect.

Reliability of the modular candidates when used in a nuclear mission is of greater concern, particularly when mated to a convertible missile that is produced with reliability levels acceptable just to conventional applications. The cost of building and certifying all the missiles and WHBs to reliability levels necessary for nuclear use will have to be incurred whether the missile system application is nuclear-only or convertible. Since the candidates are all relatively low-buy, high-value munitions, this cost should be relatively small over the total life cycle.

Reliability of the INC built at the DOE production plants, however, should still be very high. A good and simple one-stage design that underwent adequate development, testing, and production, would seem to ensure a very high reliability. In the field, the sealed INC would undergo simple electrical checks to ensure its positive status. The real question is the successful ability to insert the INC, ensure that the proper electrical interfaces have been made, check the overall weapon status, and then be ready to launch a reliable missile, all within about 15 minutes. One can imagine a very difficult environment--dry insertion in rolling seas and pitching decks or on a dark, rainy, dirty, muddy battlefield; or a rather benign environment--a shelter at a collocated Air Force base. One should keep in mind, however, that today the current Lance and Pershing 1A missiles require a physical and electrical mating of the nuclear warhead in field environments.

We think that good operational procedures can result in modular warheads with at best reliability as high as the baseline nuclear warheads, and at worst a slight degradation that is fully acceptable (especially in light of the lower missile reliability). But pending actual reliability testing of mockups and WR warheads, and given the reliability of the missile itself, we conservatively take a pessimistic view in the merit analysis with regard to system reliability.

c. Merit Estimation

Candidate	VI	U	VI x U
A	3	-0.7	-2.1
N	3	-0.5	-1.5
AF	3	-0.2	-0.6

8. Range

a. Statement

Range for the nuclear mode of convertible weapons may be less. (Army)

b. Discussion

The Navy convertible system is not range-affected because the convertible and nuclear applications

DOD

The Army system, however, may or may not carry the submunitions in a nuclear role. Downloading the submunitions would give a full nuclear range, but at a cost of time and affecting survivability, operational effectiveness, and logistics. Again, it may be more cost-effective, as noted above, to have a dedicated modular SSM for the nuclear mission instead of a convertible.

c. Merit Estimation

Candidate	VI	U	VI x U
N	2	0	0
A	2	-0.5	-1.0
AF	2	0	0

9. Deployability

a. Statement

DOD

b. Discussion

DOD

The perception of this rationale by the political leaders and populous of the host nations may be the exact opposite of this study's perception. They may believe instead that "a nuclear weapon is a nuclear weapon..." We have no idea as to the merit of modular warheads as related to these concerns except that there is now a possibility of storing, docking, and overflying modular warheads, while there is not with the baseline systems.

10. Total and Average Merit Under Operational Effectiveness

Candidate	Total Merit	Average Merit
A	+1.3	+0.1 (insignificantly better than baseline)
N	+8.7	+0.4 (somewhat better than baseline)
AF	+1.7	+0.1 (insignificantly better than baseline)

H. Logistics

The broad area of logistics includes transporation and handling, storage requirements, training, special theater movements, LLCE complexity and intervals, administrative and security regulations, component classification, maintenance and support, security personnel and storage sites, and personnel reliability and inspections. We find that in the area of logistics each of the three candidates show potential improvements over the baseline, albeit small in degree in the aggregate.

1. Transportation and Handling

a. Statement

[redacted] DDE LC

D. Discussion

Significant advantages accrue in the normal day-to-day logistical transportation and handling of INCs. The INCs can be moved easily by air or ground shipment. Convoy sizes can be reduced in numbers of vehicles and personnel because of the lower physical transportation requirements and the inherent safety of INCs. Likewise, transportation costs for initial deployment and operational and maintenance movements during the warhead's life should fall dramatically.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	2	+1	+2

2. Storage Requirements

a. Statement

The size of storage areas requiring special protection is decreased. (All three candidates)

b. Discussion

Our premise is that only the INC will contain RD information. Unlike the baseline nuclear munitions that require special nuclear storage of the entire nuclear warhead or an entire nuclear warhead mated to its missile, the nuclear storage requirements of INCs are minimal, whether it be at Army special storage sites or barracks arms rooms, Navy special magazines, or Air Force special storage sites and MOBs/COBs.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	2	+1	+2

3. Training

a. Statement

Training in unit areas and in the field can improve because of the greater availability of INC mock-up trainers and non-RD warheads. (All three candidates)

b. Discussion

The availability of training devices for the baseline munitions is limited. This limitation, plus the size and weight of the trainers, restricts the quantity and quality of hands-on training.

This problem is particularly acute for the Army baseline system. Though alert exercises train and test the units in their ability to move from the barracks environment to a full field environment,

[redacted] The design of the INCs allows for the production of numerous cheap trainers. By having these trainers at the firing unit area, the soldiers during peacetime can receive excellent training in their use by deploying to the field with their missiles, WHBs bodies (drawn from conventional ASPs), and INC trainers. The artillerymen can then train in the insertion of the INCS in the field.

Many of the same benefits accrue to the realistic training for the Navy and Air Force modular candidates. Greater availability of trainers and practice exercises can do much to alleviate the reliability problems and time requirements that we examined previously.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	2	+1	+2

4. Special Theater Movements

a. Statement

Transportation of INCs into special theaters can be more rapid and secure than full-up nuclear munitions. (All three candidates)

b. Discussion

[redacted]

c. Merit Estimation

Candidate	VI	U	VI x U
A, AF	3	+1	+3
N	2	+1	+2

5. Limited-Life Component Exchange (LLCE) Complexity

a. Statement

Limited-life component exchange is easier. (All three candidates)

b. Discussion

[redacted] This operation has a sizeable impact upon logistic efforts and operational readiness.

The small size and weight of INCs plus their greater accessibility for maintenance is an advantage over the baseline system. The change-out process can be conducted more rapidly and with less maintenance man-hours.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	1	+1	+1

6. Administrative and Security Regulations

a. Statement

Administrative and security regulations must be adapted to engender viability of modular weapons in all utility areas (except safety, which is inherently increased). (All three candidates)

b. Discussion

The overall utility to be derived from the candidate modular systems largely depends upon modifying current administrative and security regulations. Current restrictions come mainly from the DoD Directive on security criteria.[29] As currently written, this policy means that all components of a modular warhead would inherit the same restrictions as the baseline nuclear systems: two-man rule, large security forces, substantial storage requirements, and concentrated storage at special sites.

We think that our preferred one-stage design approach can satisfy all the safety and security objectives behind current administrative regulations within the SLSs sequences noted previously. We also believe that the intent of the regulations and directives can be fully satisfied by using the modular systems under a newly adapted set of regulations and directives. Nevertheless, we recognize that institutional inertia within the security community (which is common to all large organizations) to keep the same administrative and logistic systems must be overcome. Probably the best way is to provide mock-up point designs (paralleling the DOE Phase 2 and 3 efforts) to the safety, security, and logistic experts who would determine acceptability and work out these modifications. Evolutionary change of these regulations is the only forseeable path that is politically acceptable at this time. Nevertheless, failure to adapt regulations to account for the singular differences of modular weapons from those of standard nuclear weapons would result in disutility greater than that indicated by the merit estimation in this subarea.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	3	-1	-3

7. Component Classification

a. Statement

The WHB body must not carry a classification higher than its delivery missile. (All three candidates)

b. Discussion

This concern parallels the one above, but needs to be spelled out to allow early field and collocated base deployment of the Army and Air Force candidates.

Current classification is:

[redacted]

DOE 6(3)

[redacted]

DOE 6

[redacted] This is not critical since it will be on a secure container for most of its life.

[redacted]

DOE 6

This is not to say that NCA release and reliable secure communications will no longer be needed to insert the RD INC into the WHB. Sealed authenticators will still be required along with PAL devices on the INC container and even possibly on the complete warhead system after release is granted.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	3	-1	-3

8. Maintenance and Support

a. Statement

Maintenance and support workload and handling equipment are reduced for the INC. (All three candidates)

b. Discussion

A primary logistic consideration is maintenance. The one-stage design approach should mean that the using unit would only need to make visual inspection and simple electrical checks to ensure that no unauthorized actions had occurred. By keeping the design of the WHB body and INC as simple as possible, maintenance workload should be reduced because of easier access and less sophisticated tests. Normal stockpile maintenance and testing of the interfaces between the explosives and warhead electrical system would be eliminated until mating of the INC occurs during war. Large handling equipment requirements would no longer exist for maintenance of the INC because of its small size. The Navy candidate may also result in some maintenance (and transportation) reduction by not having to send the whole canistered nuclear Harpoon back to depot as the baseline system requires. The dispersal of Army INCs to unit arms rooms (or within security wells, safes, etc.) might require transient maintenance sections to visit the dispersed locations. However, the reduction in workload at the special nuclear sites should offset the personnel requirements for the transient sections. Another alternative is to assign these "go/no-go" checks to the operational crew at the firing units.

Maintenance may rise, however, because additional equipment will be deployed for modular warhead support:

Army INC containers, secure storage at firing batteries (wells, safes, etc.), test equipment

Navy INC containers, test equipment

Air Force INC containers, deployable secure storage assets (transporters, moveable igloos, etc.), test equipment

Additional procedures and administrative guidance would be needed. The modular systems would require their own checklists, repair parts, and special tools.

c. Merit Estimation

Candidate	VI	U	VI x U
A	2	+0.2	+0.4
N, AF	2	+0.4	+0.8

9. Security Personnel and Storage Sites

a. Statement

Numbers of security personnel will generally be unchanged unless current storage sites become INC-only sites. However, security personnel requirements and storage sites will increase if unit storage is allowed. (Army, Air Force)

b. Discussion

As long as the number of storage sites remain constant and include baseline nuclear weapons, then the number of guards will remain unchanged.

The use of the Army modular candidate would cause the dispersion of SSM INCs away from current fixed sites into the arms rooms of the firing units. The fixed sites, however, would still require protection for the AFAPs, ADMs, and Pershings. We see no hope for reductions in guard forces at these sites, unless these sites are consolidated (with a loss of survivability) or some weapons are removed back to CONUS. An argument can be made that security forces may increase, as the quantity and quality of arms rooms guards might be insufficient. Given current FA and AD artillery TOEs, this concern is a valid one.

Security manning for the Navy modular system afloat would remain the same. Peacetime security for the Air Force system would also parallel present requirements; however, crisis deployment to COBs and/or airstrips would have to draw on additional personnel.

Security during normal peacetime transportation movements could be reduced as noted earlier. Convoy security force requirements (infantry units) are substantial and detract from normal training.

c. Merit Estimation

Candidate	VI	U	VI x U
A, AF	2	-0.7	-1.4
N	3	0	0

10. Personnel Reliability and Inspections

a. Statement

Requirements for personnel reliability programs and inspections will probably remain the same. (All three candidates)

b. Discussion

The same high level of personnel competence that currently exists for the baseline warhead systems would apply to the modular candidates. Personnel involved in the authentication system and insertion of the nuclear component would still remain in critical nuclear duty positions. Those involved in the security of the INC would still be in controlled nuclear duty positions. The need for records, operational procedures, and maintenance would have an impact on the three modular candidates to the same degree as it presently does.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	2	0	0

11. LLCE Intervals

a. Statement

LLCE intervals and stockpile life will remain the same. (All three candidates)

b. Discussion

No differences can be identified between the modular warhead candidates and the baseline nuclear systems in regard to LLCE intervals or stockpile life.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	1	0	0

12. Total and Average Merit Under Logistics

Candidate	Total Merit	Average Merit
A	+3.0	+0.1 (insignificantly better than baseline)
N	+3.8	+0.2 (slightly better than baseline)
AF	+3.4	+0.2 (slightly better than baseline)

[redacted]

c. Merit Estimation

Candidate	VI	U	VI x U
N	3	+1	+3
A, AF	N/A		

2. SNM Requirements

a. Statement

Convertible warheads require slightly higher amount of SNMs than non-convertible warheads of the same yields. Nuclear-only INC warheads, however, are about as efficient in the use of SNM as standard nuclear warheads. (All three candidates)

b. Discussion

Previous studies have indicated that INC warheads require more SNM than standard warheads, all other things being equal. [redacted]

Two resource considerations also apply to SNM usage--cost and supply/demand. The costs are set by decree and may not reflect SNM's true value. [redacted]

[redacted]

DOE

Clearly, major changes in RD&T costs have little impact upon life-cycle cost. With a straightforward simple design, nuclear testing can be held to a minimum. We do not foresee much change in RD&T costs as compared to baseline nuclear system costs. [redacted]

DOD [redacted]

Production costs for the warheads (DOE and DoD) may show some additional cost expenditures over the baseline systems. This is due to producing a "different" type of warhead. New tooling and facilities will be necessary. Direct unit costs of manpower and material for the warhead will probably be very similar to the costs of baseline systems. Cost savings may be realized through using a simpler and less expensive final assembly at the Pantex Plant.

c. Merit Estimation

Candidate	VI	U	VI x U
A, N, AF	2	-0.2	-0.4

4. Safe Secure Containers and Storage Facilities

a. Statement

Production of safe secure containers and construction of associated storage facilities may be expensive, particularly for the Army system. (All three candidates)

b. Discussion

As noted in the Harpoon studies,[10,30] the real crux of production cost increases lies in the requirements for safe secure containers (all three modular candidates), construction of new storage facilities (wells, igloos, air-transportable shelters), and secure transporters. [redacted]

DOD

[redacted] The Navy requirement for this extra equipment is less than the Air Force's or Army's. [redacted]

[redacted]

DOD [redacted] Perhaps C-130 transportable shelters could be procured, or perhaps C-130 transportable versions of safe, secure trailers could be used. (The TASM with WHB less INCs would be carried by the flushed fighter aircraft).

DOD [redacted]

c. Merit Estimation

Candidate	VI	U	VI x U
N	2	-0.2	-0.4
AF	2	-0.4	-0.8
A	2	-0.7	-1.4

5. Missile System Operation and Support Costs

a. Statement

Missile system operation and support costs account for about [redacted] of DOD weapon total life-cycle costs. (If the delivery unit life-cycle cost is considered, then the cost of INCs becomes practically negligible in terms of total life-cycle cost.) The cost may rise in certain areas and fall in others. The overall effect is highly dependent upon INC storage schemes and security regulations, especially for the Army system. (All three candidates)

b. Discussion

Operation and support include the areas of security, maintenance, transportation, reliability testing, and staff support. As noted previously, about DOD [redacted] of the life-cycle cost is for operation and support and [redacted] of DOD operation and support costs are security related. The impact upon operation and support costs by the modular candidates will be a function of the percentage of stockpile that is converted to modular systems, the distribution of them among storage sites, and the type of storage and operational concepts adopted.

DOD [redacted] DOE 6(3)

DOE b(3)

DOL

Transportation is one operation and support area where significant savings should be realized. First- and second-destination transportation, operational moves, and transportation to depot for maintenance are expensive in dollars and transportation assets. Convoy sizes and aircraft sortie requirements can fall greatly because of the small INC volume and weight, [redacted] and the inherent safety and security by having the nuclear material separate from the main explosives.

Reliability testing and stockpile support will probably remain the same.

c. Merit Estimation

For the merit analysis, we use the relative importance of each subcategory:

Candidate	VI	U	VI x U
Security			
A	2	-1.0	-2.0
N	2	0	0
AF	2	-0.5	-1.0

[redacted]

Maintenance			
A	1	-0.5	-0.5
N	1	0	0
AF	1	0	0
Transportation			
A, N, AF	1	+1.0	+1.0
Reliability Testing/ Staff Support			
A, N, AF	1	0	0

6. Total and Average Merit Under Costs

Again for the merit analysis, we use the relative importance of each cost category.

Candidate	Total Merit	Average Merit
A	-3.7	-0.3 (somewhat worse than baseline)
*N	+2.8	+0.2 (slightly better than baseline)
AF	-1.6	-0.2 (slightly worse than baseline)

*Fewer modular missiles procured because of convertibility.

J. Summary Merit Analyses

Preceding sections have described the advantages and disadvantages of the three modular weapon candidates. At the end of each section we summarized the quantitative merit based upon the analyzed information. For convenience, the data on average merit are presented below.

Area/Candidate	VI	Army	Navy	Air Force
Safety	2	+0.3	+0.5	+0.3
Security	2	+0.2	+0.5	+0.2
Survivability	3	+0.6	+0.1	+0.6
Operational Effectiveness	1	+0.1	+0.4	+0.1
Logistics	1	+0.1	+0.2	+0.2
Costs	1	-0.3	+0.2	-0.2

By combining the major area average merits, we can arrive at a summary ranking that is useful for comparison between the modular candidates themselves and for comparisons between the baseline weapon systems. First we must

rank the worth of the areas; then we must carry out the simple math. We maintain that the area of survivability is of overriding importance, and we assign a VI of 3, or "extremely important". We rank safety and security next with a VI of 2, or "very important." Operational effectiveness, logistics, and costs are considered to be of "some importance" and are assigned a VI of 1. We arrive at the following figures by multiplying the VI times the average merit for each area, sum the six areas, and divide by the sum of the VIs (10).

Candidate	Average Merit
A	+0.27 (somewhat better than baseline)
N	+0.31 (somewhat better than baseline)
AF	+0.29 (somewhat better than baseline)

There is a striking similarity in average merit between the modular candidates, perhaps because they all have tactical missions and many subareas show utility regardless of the application (for example, plutonium-scatter safety). All three candidates display good potential towards improving the tactical nuclear stockpile; any or all bear continued consideration for addition to the inventory.

CHAPTER VI

REVIEW OF PERTINENT REGULATIONS AND DIRECTIVES

A. General

Providing for safety in handling nuclear weapons is a joint responsibility of the DoD and DOE. The DoD is also responsible for providing secure custody of the nuclear weapons under its control. [redacted] The facilities and procedures prescribed by these directives are accordingly elaborate and require substantial resources. The question raised by the possibility of deploying weapons with INCs is whether the required resources for ensuring safety and security could be thereby materially reduced. That question is discussed in this chapter. A bibliography is shown below:

DOD DIRECTIVES

5210.41	Security Criteria and Standards for Protecting Nuclear Weapons

Miscellaneous Publications

JCS Pub. 6, Vol. II, Part 4	Nuclear Weapons Reports (NWREP)
SB 742-1	Ammunition Surveillance Procedures
ARTEP 9-47	Special Ammunition Unit Operations
CG-W-4	Nuclear Weapon Classification Guide
DOE-DNA TP 0-1	Numerical Index to Joint Nuclear Weapons Publications

Department of the Army Publications

Army Regulations (ARs)

50-5	Nuclear Surety
50-5-1	Nuclear Surety (classified volume to AR 50-5)
50-109	Safety Rules for the Operation of the Lance Nuclear Weapons System
55-203	Movement of Nuclear Weapons, Nuclear Components, and Related Classified Nonnuclear Material

190-11	Physical Security of Weapons, Ammunition, and Explosives
385-64	Ammunition and Explosives Safety Standards
700-65	Nuclear Weapons and Nuclear Weapons Material

Field Manuals (FMs)

9-6	Ammunition Service in the Theater of Operations
9-84	Nuclear Special Ammunition Direct and General Support Unit Operations
19-30	Physical Security
100-50	Operations of Nuclear-Capable Units

Technical Manuals (TMs)

9-1300-206	Ammunition and Explosives Standards
39-0-1A	Numerical Index to Joint Nuclear Weapons Publications (Army supplement)
39-20-7	Nuclear Safety Criteria
39-45-51	Transportation of Nuclear Weapons Material
39-50-8	Emergency Destruction of Nuclear Weapons
39-100-4	Custody, Accountability, and Control of Nuclear Weapons and Nuclear Material
55-1425-485-15-1	Transportability Guidance Lance Missile System

Technical Bulletins (TBs)

9-1100-803-15	Army Nuclear Weapons Equipment Records and Reporting Procedures
9-1100-811-40	Security Classification of Nuclear Weapons Information
742-94-1	Surveillance Inspection Procedures for Nuclear Weapons

Department of the Navy Publications

OPNAV Instructions (OPNAVINSTs)

8023.2A	U.S. Navy Explosive Safety Policies, Requirements and Procedures
8023.19	Safety Criteria and Standards for the Logistical Movement of Nuclear Weapons
8110.18	Navy Nuclear Weapons Safety Program

Special Weapons Ordnance Publications (SWOPs)

20-7	Nuclear Safety Criteria
45-55	Instructions for Tactical Movement of Ground-Delivered Nuclear Weapons

against the presumed disadvantages of making procedural exceptions. The advantages of modular systems are discussed in earlier chapters of this study. Each service would identify for itself the disadvantages of allowing departures from practices that have long been followed in the care and handling of its nuclear weapons.

C. Expectation for Change in Handling Procedures

It does not seem likely that the military services will change their procedures for handling nuclear weapons before a modular system is fielded. Therefore, the first modular system cannot be designed to accommodate changes that will be made in those procedures after the system is fielded, if any such changes are made. It does not appear that the development of modular technology is hindered by present directives or procedures. If modular systems are designed to be handled exclusively in accordance with presently prescribed methods, however, the presumed advantages of fielding such systems will not be fully realized.

The preferred SLS for the Army modular candidate would continue the present practice of deployment of missiles and launchers to survivable field locations during training and alerts. The non-RD WHB would also deploy on the missile with the units.

2. Security. Security is a condition that results from the establishment of measures to protect designated information, personnel, systems, components, and equipment against hostile persons, acts, or influences. Several technical and operational advantages of varying importance accrue to modular warheads. The primary operational advantage lies in the fact that, for most of their life, security requirements are on components that are neither full-up nuclear weapons nor able to produce a nuclear yield.

Security Merit Assessment

Army	= +0.2	Slightly better than baseline
Navy	= +0.5	Better than baseline
Air Force	= +0.2	Slightly better than baseline

movements, training, LLCE, administrative and security regulations, component classification, security personnel, and personnel reliability and inspections. Throughout the study we used the SLSs that were defined under a favorable environment and found slight improvements in the three modular candidates.

Logistics Merit Assessment

Army	= +0.1	Insignificantly better than baseline
Navy	= +0.2	Slightly better than baseline
Air Force	= +0.2	Slightly better than baseline

6. Costs. Life-cycle costs including development, production, operation, and support were examined in a relative context. Though absolute cost numbers were not estimated, the merit assessment qualifies the broad cost trends. The Navy's convertible force should cost less than the baseline if fewer Harpoon missiles are procured for the convertible force. The Army and Air Force modular candidates are thought to cost more, primarily because of increases in production, security, and storage costs.

Costs Merit Assessment

Army	= -0.3	Somewhat worse than baseline
Navy	= +0.2	Slightly better than baseline (fewer modular missiles procured because of convertibility)
Air Force	= -0.2	Slightly worse than baseline

7. Merit Assessment Summary

By combining the major area average merits, we can arrive at a summary ranking that is useful for comparisons between the modular candidates themselves and for comparisons between the individual baseline weapon systems. We maintain that the area of survivability is of overriding importance, followed next by safety and security. Operational effectiveness, logistics, and costs are of lesser relative importance.

There is a striking similarity in merit between the modular candidates; all are deemed to be "somewhat better than baseline." The Navy modular candidate gives a summary merit of +0.31, followed closely by the Air Force and Army modular candidates at +0.29 and +0.27, respectively.

C. Recommendations

Increases in survivability should be the primary reason for developing, producing, and deploying modular nuclear warheads. In addition, safety stands out as the single area where INC benefits are unequivocal regardless of the administrative and security environment that evolves for modular warheads. Although the benefits of having safer warheads are of great importance, we realize that modern standard warheads have an unblemished safety record regarding accidental nuclear detonation; however, [redacted] The real benefits in safety improvements lie in allowing changes in the transportation and storage of nuclear weapons that can result in greater dispersion and enhanced survivability.

Several earlier studies and the analyses conducted here indicate the potential utility of a modular system. A careful and logical development process for any of the three modular candidates can lead to exploiting the benefits noted while minimizing the disadvantages. Three specific recommendations are made:

(1) Recommend that the Los Alamos National Laboratory (Los Alamos) develop mockups or point designs for appropriate service generic systems to enable the services to evaluate the operational, logistic, safety, security, survivability, and system cost impacts of INC or convertible systems.

(2) Recommend that Los Alamos continue to develop concepts for engineering designs to support modular systems in support of identified or perceived service requirements.

(3) Finally, based upon specific service stated requirements, recommend that Los Alamos be prepared to develop modular warheads for production and employment.

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On the Impact of Nuclear Science for Nuclear Weapons Physics

Morgan White

Los Alamos National Laboratory

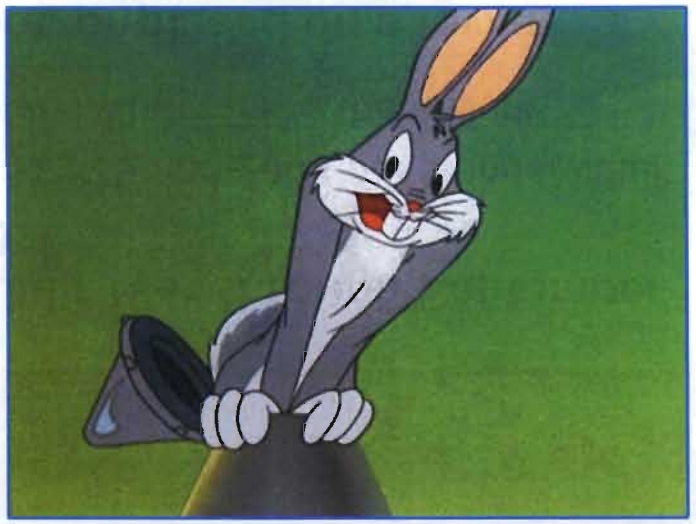
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Presentation to the LANSCE User Group, January 9, 2012

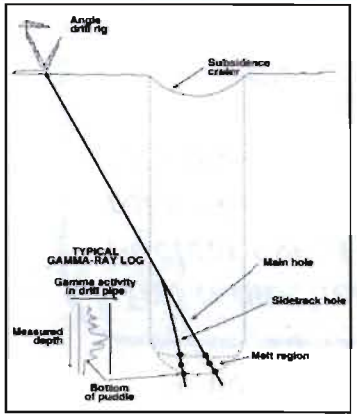
So What's All The Hubbub, Bub?
The Gaps In Our Understanding Of Nuclear Science

- **Nuclear science plays a key role in both the physics of nuclear weapons performance and the diagnostics used to quantify the same**
- **In an era of no nuclear testing, reduced uncertainties are required on many nuclear physics parameters**
  - Both to achieve the required simulation accuracy and to interpret experimental data
- **While there is a rich history within the field, measurements of many quantities show significant discrepancies and measurements still do not exist for many key quantities**
  - For example, the fission product yields
- **There is still much to be done**

I'm multiplyin', Doc! I'm multiplyin!



Radiochemical Analysis Process

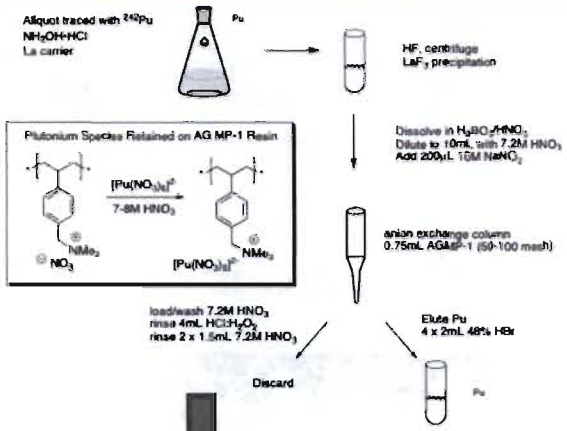


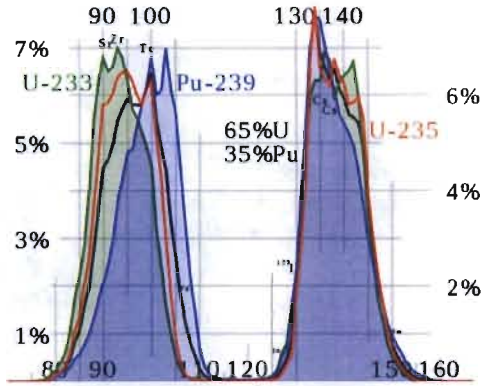
Sample recovery



Collections consist of complex mixtures:

- **Homogenization**
- **Dissolution**
- **Separation**
- **Assay**





Not really this simple – other corrections apply

$$e = \frac{\text{fissions}}{\text{Original atoms of fuel}}$$

$$e = \frac{F}{F + p}$$

If total fuel known, can calculate total fissions (F_T), or energy release

"*Measure fissions*" in the sample, F

Measure unburned fuel atoms, p

UNCLASSIFIED

Radiochemical Quantifies Device Performance

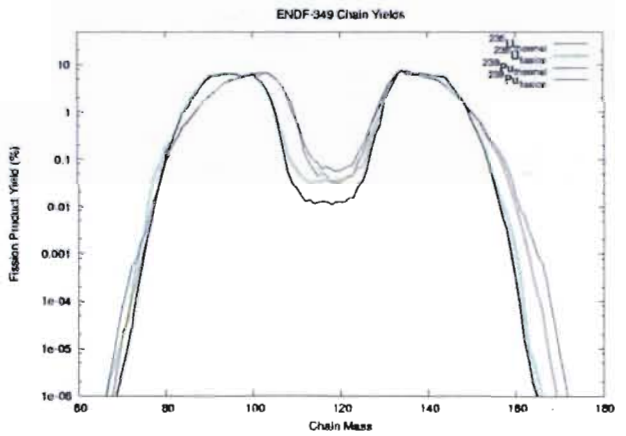
- **Radiochemical diagnostics are time integrated measurements**
- **There are three major classes of analytes that are determined by radiochemistry**
  - Actinides
  - Fission Products
  - Activation Products

The radiochemical interpretation of a nuclear event from fission products relies on the ability to determines fissions :

$$N_i = FY_i \qquad F = N_i / Y_i$$

N_i = *number of atoms of fission product i*
Y_i = *cumulative fission product yield*





FPY (fission product yield) %

A_i mass of fission product

Predictions And Data For "Bomb Thermal" From LA-3403 (U) Cross Section Measurements on Parrot

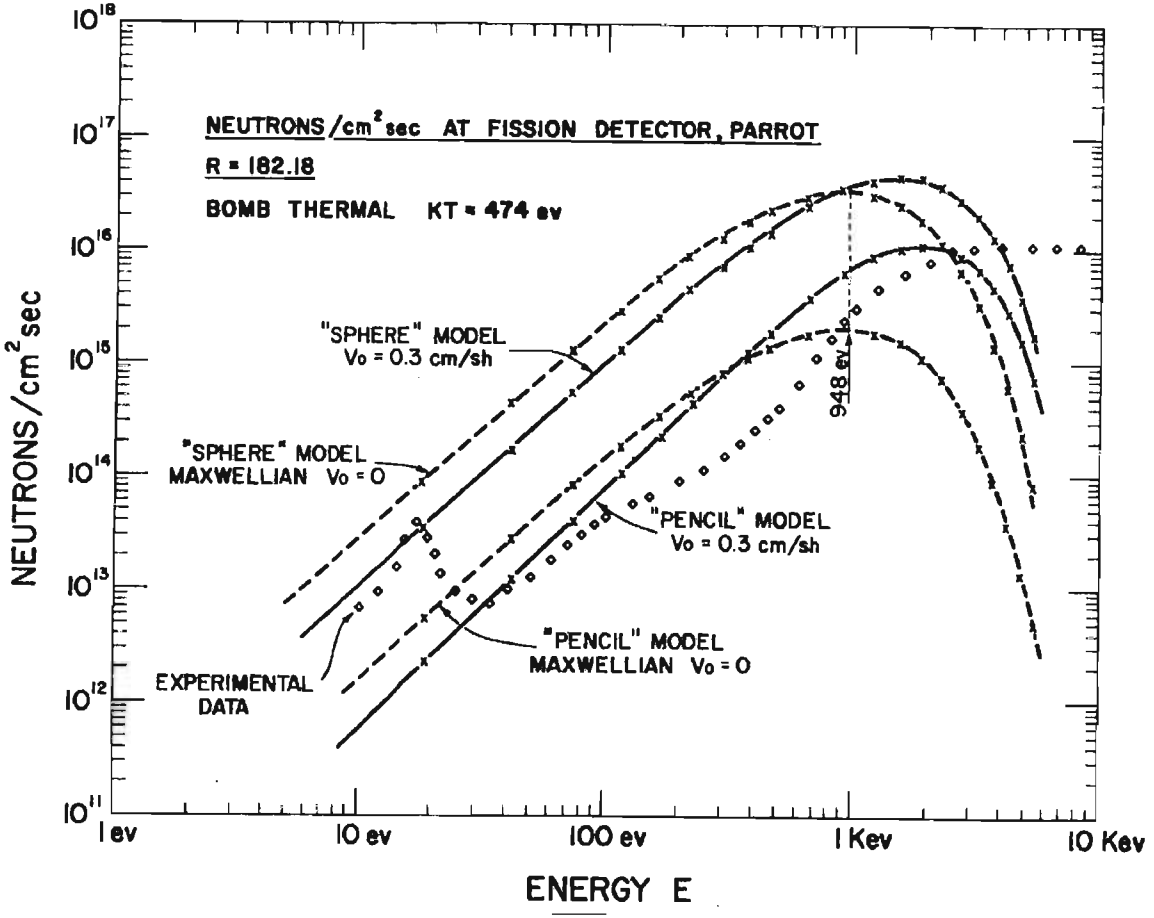


FIG. 6. THERMAL NEUTRON SPECTRA. BOMB THERMAL KT = 474 ev.

LA-3403
UC-34, PHYSICS
TID-4500 (45th Ed.)

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California

LOS ALAMOS • NEW MEXICO

Report written: August 1965

Report distributed: November 12, 1965

Thermal Neutron Spectra from an Underground Nuclear Explosion with Special Consideration of Spectral Modification due to Bomb Debris Motion

by

Henry A. Sandmeier and Gordon E. Hansen



ABSTRACT

The neutron flux from an underground nuclear explosion has recently been used to measure nuclear cross sections. For the experimenter it is of interest to know the neutron spectrum and intensity emerging from the top of the pipe leading to the nuclear device.

A short time following the nuclear explosion and after many fast neutrons have escaped, the local neutron spectra in the bomb debris will be in thermal equilibria. The spectrum of neutrons leaking from this debris will depend on a superposition of these local Maxwell Boltzmann distributions each with its characteristic drift velocity $\vec{v}_o$.

Theoretical expressions are derived for the low energy neutron spectrum emerging from a long narrow pipe. The theoretical predictions agree reasonably well with measurements obtained from the Parrot Shot in Nevada in the Spring of 1965.

ACKNOWLEDGMENT

We would like to thank our colleagues, Walter Goad and George Bell, for their help in this investigation.

I. INTRODUCTION

The problem to be solved is: given a spherical ball of bomb debris moving radially outwards with material velocity $\vec{v}_o$ and containing neutrons in local thermal equilibria, then what is the neutron spectrum on top of a long narrow pipe of length R and radius η (Fig. 1). It is assumed that the debris density has become so small that no further neutron collisions will occur; in other words, the neutrons do not find a diffusive medium anymore. The neutrons are therefore liberated from a moving source containing "bottled up" neutrons with local Maxwell Boltzmann distributions. The spectrum on top of the pipe will depend on how much one "sees" of the bomb debris sphere looking down the long narrow pipe. This problem has been discussed previously by Nordheim,[1] as well as Bell.[2] This paper looks at the problem in a more general way, and the case treated by Nordheim and Bell becomes here a special case where the observer looking down the pipe sees only a "pencil" of the bomb debris sphere.

---

[1] L. W. Nordheim: Neutron Spectra from a Moving Source, Los Alamos Scientific Laboratory Memorandum, July 30, 1964, and Addendum, July 22, 1964.

[2] G. I. Bell, private communication, August 19, 1964.

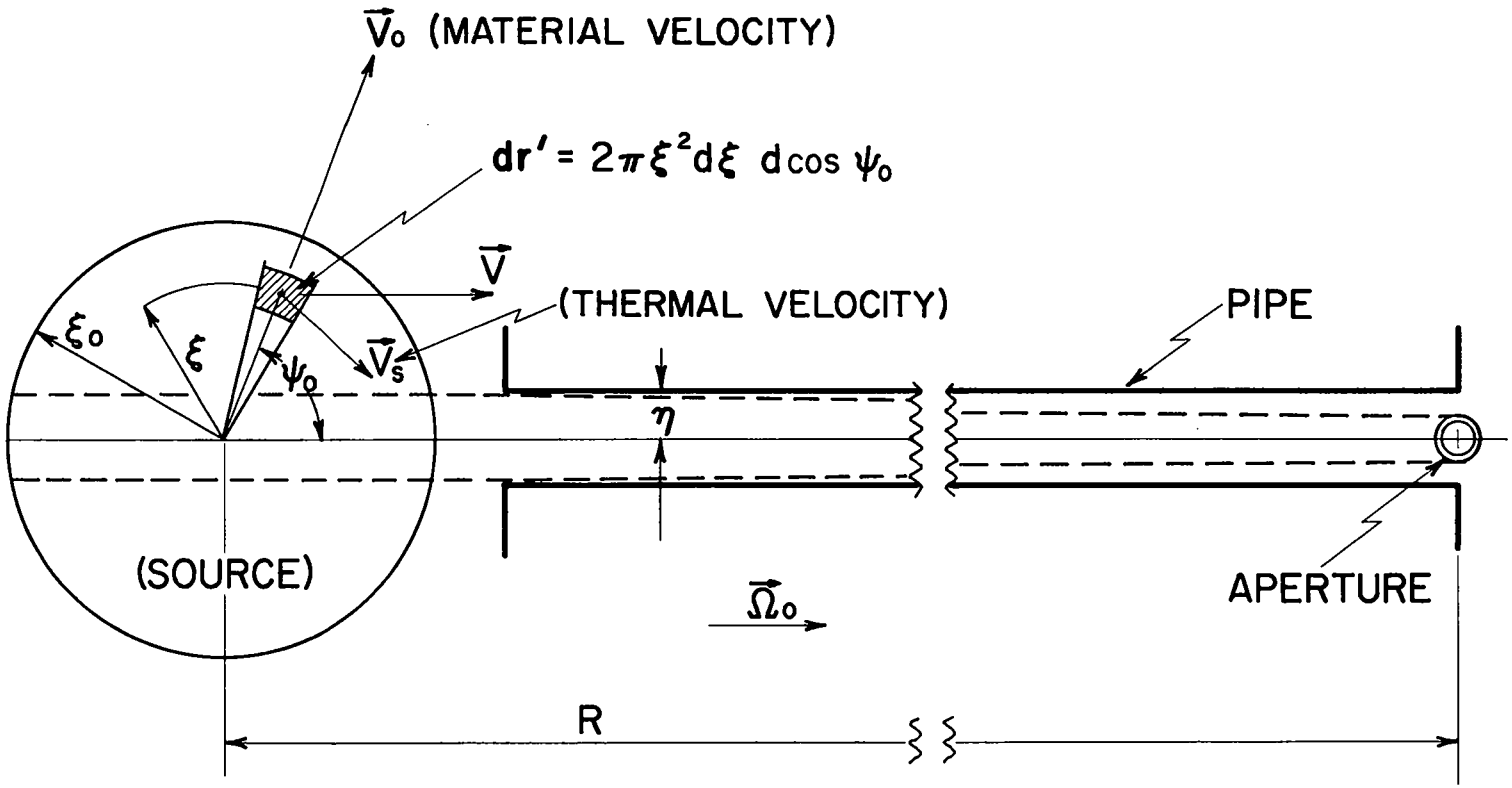


FIG. 1. SCHEMATIC OF DEBRIS SPHERE AND PIPE.

II. THERMAL NEUTRON SPECTRA FROM A RAPIDLY EXPANDING MATERIAL SPHERE

The initial neutron density in the debris is assumed to be a Maxwell-Boltzmann distribution.

$$n(\vec{v}_s) = ce^{-\frac{1}{2}m\frac{(\vec{v}-\vec{v}_o)^2}{KT}} = ce^{-\frac{1}{2}\frac{m\vec{v}_s^{\,2}}{KT}} \qquad \text{EQN 1}$$

Here the drift velocity is equal to the material velocity $\vec{v}_o$, and $\vec{v}_s$ is the neutron velocity relative to $\vec{v}_o$. In Appendix A we derived an expression for the number of neutrons passing through the unit area perpendicular to direction $\vec{\Omega}_o$ at R (Fig. 1) in the time interval ΔT about T. The initial neutron population $n(\vec{r}',v,\vec{\Omega}_o,0^+)$ in Eqn. A-14 created by the δ-function source becomes

$$n(\vec{r}',v,\vec{\Omega}_o,0^+) = c(\vec{\xi})e^{-\frac{1}{2}\frac{m}{KT}[v^2+v_o^{\,2}-2vv_o\cos\psi_o]} \times v^2 \qquad \text{EQN 2}$$

and Eqn. A-14 becomes

$$J_o(\vec{r},T)\Delta T = \int_{\text{source}} 2\pi\xi^2 d\xi\, d\cos\psi_o\, c(\vec{\xi})e^{-\frac{m}{2KT}[v^2+v_o^{\,2}-2vv_o\cos\psi_o]} \times v^2 \frac{\Delta v}{R^2} \qquad \text{EQN 3}$$

V. NUMERICAL EVALUATION OF "PARROT" ESCAPE SPECTRUM

The experimental set-up (Fig. 5) has been described in the open literature.[3]

The numerical values for the quantities shown in Fig. 5 are listed below. These values are subsequently used to numerically evaluate Eqn. 14 "pencil" model and Eqn. 16 "sphere" model.

$N_o = 0.06848 \times 10^{24}$	"Parrot" neutrons released in thermal equilibrium
$V_o = 5.24 \times 10^5$ cm^3	Bomb debris "sphere" volume at time of neutron release
$U_o = 3.24 \times 10^4$ cm^3	Bomb debris "pencil" volume at time of neutron release
R = 182.18 m	Distance bomb debris center to fission foil detector of area $\pi r^2 = 1.037$ cm^2 pipe radius $\eta = 10.16$ cm
Y = 1.2 KT	Total yield of "Parrot"
KT = 474 ev	Bomb thermal temperature
$v_o = 0.3$ cm/sh	Material velocity

These individual quantities shown in Fig. 5 will now be discussed briefly.

---

[3] "Neutron Time of Flight Experiments Using Nuclear Explosions," B. C. Diven. Submitted and to be published in Oct. 1965 issue of SCIENCE.

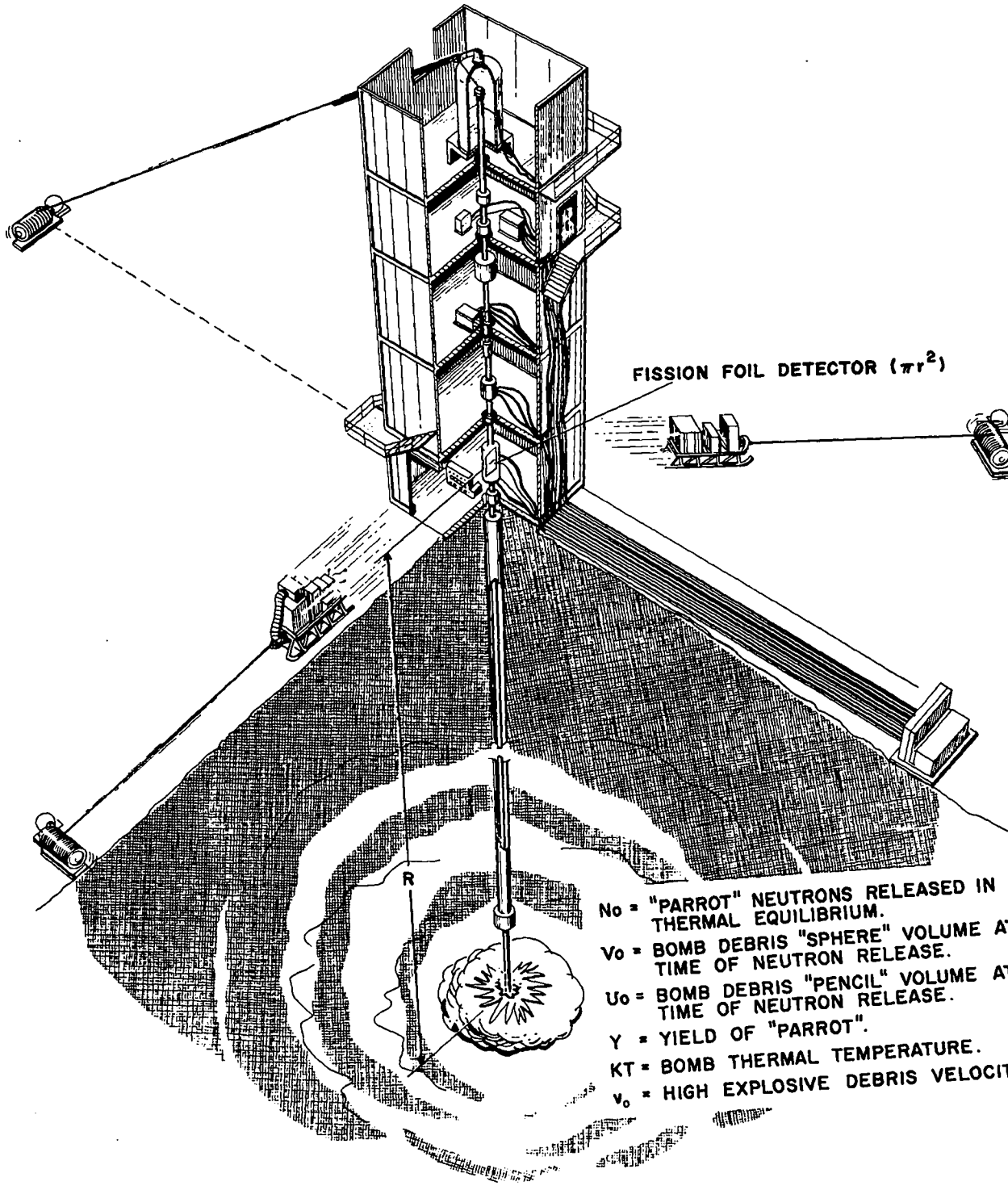


FIG. 5. UNDERGROUND NUCLEAR TEST "PARROT."

a. N_o, Parrot neutrons released in thermal equilibrium; v_o, debris velocity and KT, Parrot bomb thermal temperature.

In a nuclear device a configuration of fissionable material is driven together by exploding the surrounding high explosive layer.

The assembled configuration will reach supercriticality and the released fission energy will cause the rapid expansion of the bomb. The debris will move radially outward, including the hydrogeneous remnants of the high explosive layer. Before the high explosive moderator or reflector moves away, it is assumed that the fission neutrons born have come to a thermal equilibrium by collisions with the bomb debris.

During the expansion phase a time will be reached where the surrounding moderator (high explosive remnants) comes to such a low density that the thermal neutrons will cease to make collisions with the high explosive debris. We are therefore confronted with the problem to determine the neutron spectrum coming from a moving source, as seen in the Laboratory system. The material velocity v_o of the debris becomes the source velocity of the "bottled up" thermal neutrons.

From coupled hydrodynamics--neutronics calculations--the number of thermal neutrons N_o can be determined as well as the velocity v_o of the high explosive debris. A reasonable estimate of the HE debris velocity v_o at the time of thermal neutron release is 0.3 cm/shake. The debris temperature may now be deduced by using the fact that, behind a strong shock, internal energy per gram equals kinetic energy per gram: for the

essentially completely ionized HE components, this translates to $v_o \simeq \sqrt{2KT/m}$ with m still representing the mass of one neutron. We thus obtain $KT \simeq 474$ ev.

b. Pencil and sphere volume, V_o and U_o.

The volume of the debris sphere U_o, as well as the pencil volume V_o, is determined from the same calculations mentioned previously. The sphere volume V_o is the configuration in which the mean free path for thermal neutrons in the high explosive remnants becomes so large that it will no longer act as a diffusive medium for thermal neutrons.

c. Depth of underground nuclear explosion, R.

The quantity of interest in this report is R = 182.18 m and the foil area $\pi r^2 = 1.037$ cm^2. The fixed aperture area just below ground level is 0.9698 cm^2. The fission foil is a few feet above ground level.

d. Evaluation of "pencil" and "sphere" neutron spectrum.

Equations 14 and 14a, and Eqns. 16 and 16a are evaluated for even steps in the dimensionless variable $\upsilon = v/v_o$ (Table 1). For $\upsilon = 1$ the neutron velocity v traveling up the pipe is equal to v_o, the debris velocity. Table 1 assumes a bomb thermal temperature of 474 ev. Columns 2 through 8 are evaluated from the following relationships

$$v = \upsilon \times v_o = 0.3\upsilon \text{ (cm/sh)}$$

$$\Delta v = \Delta\upsilon \times v_o = 0.3\Delta\upsilon \text{ (cm/sh)}$$

$$E(\text{Mev}) = \frac{[v(\text{cm/sh})]^2}{(13.827)^2}$$

$$\Delta E(\text{Mev}) = v(\text{cm/sh})\ \Delta v(\text{cm/sh})\ \frac{2}{(13.827)^2}$$

$$T(\text{sh}) = \frac{R(\text{cm})}{v(\text{cm/sh})} = \frac{1.8218 \times 10^4}{v(\text{cm/sh})}$$

$$\Delta T(\text{sh}) = \frac{R(\text{cm})\Delta v(\text{cm/sh})}{[v(\text{cm/sh})]^2} = \frac{1.8218 \times 10^4\ \Delta v(\text{cm/sh})}{[v(\text{cm/sh})]^2}$$

Note that the intervals Δv, ΔE and ΔT follow from the arbitrarily chosen interval $\Delta \upsilon$.

The numerical expression to evaluate $J_o(\vec{r},T)$ in Table 1 for all models and assumptions are listed below.

"Pencil" model; $v_o = 0.3$ cm/sh; $v_o = \sqrt{\frac{2KT}{m}}$

Table 1, Column 9. $KT = 474$ ev.

From Eqn. 14 we get

$$\pi r^2 J_o(\vec{r},T)\Delta T = 1.1878 \times 10^{12}\ \upsilon^2 \Delta\upsilon \left[e^{-(\upsilon-1)^2} + e^{-(\upsilon+1)^2} \right] \qquad \text{EQN 17}$$

- -

"Pencil" model; $v_o = 0$, Maxwellian; $\sqrt{\frac{2KT}{m}} = 0.3$ cm/sh

Table 1, Column 10. $KT = 474$ ev.

From Eqn. 14a we get

$$\pi r^2 J_o(\vec{r},T)\Delta T = 8.7985 \times 10^{-11}\ v^2 \Delta v e^{-1.1111 \times 10^{-15}\ v^2} \qquad \text{EQN 18}$$

"Sphere" model; $v_o = 0.3$ cm/sh; $v_o = \sqrt{\frac{2KT}{m}}$

Table 1, Column 11. $KT = 474$ ev.

From Eqn. 16 we get

$$\pi r^2 J_o(\vec{r},T)\Delta T = 9.6047\times10^{12}\, \upsilon^2 \Delta\upsilon \left\{\frac{1}{\upsilon}\left[e^{-(\upsilon-1)^2} - e^{-(\upsilon+1)^2}\right]\right\} \quad \text{EQN 19}$$

"Sphere" model; $v_o = 0$, Maxwellian; $\sqrt{\frac{2KT}{m}} = 0.3$ cm/sh

Table 1, Column 12. $KT = 474$ ev.

From Eqn. 16a we get

$$\pi r^2 J_o(\vec{r},T)\Delta T = 1.4263\times10^{-9}\, v^2 \Delta v\, e^{-1.1111\times10^{-15} v^2} \quad \text{EQN 20}$$

For our case $\pi r^2 = 1.037$ cm^2 and ΔT is taken from Table 1.

The last four columns of Table 1, as well as the experimental data, are plotted in Fig. 6.

The experimental data agree reasonably well with the calculated pencil model values. The neutron flux is "contaminated" with "reflected" neutrons which are not included in our calculations. The first peak at 18 ev is probably due to reflected neutrons from the bottom of the hole which picked up some energy from the "pre-heated" lining of the cavity. At higher energies above 3 kev we get the neutrons which have been slowed down from higher energies. This energy range is not included in this discussion, as we limited ourselves to the thermal part.

u	Δu	v (cm/sh)	Δv (cm/sh)	E	ΔE (ev)	T (msec)	ΔT (μsec)	$J_o(\vec{r},T)$ Neutrons/cm^2 sec; KT = 474 ev; R = 182.18 m			
								"Pencil"		"Sphere"	
								v_o=0.3 cm/sh	Maxwell v_o=0	v_o=0.3 cm/sh	Maxwell v_o=0
0.1	0.05	0.03	0.015	0.47 ev	4.71	6.073	3030	1.405×10^{11}	3.742×10^{11}	2.242×10^{12}	6.067×10^{12}
0.2	0.05	0.06	0.015	18.8 ev	9.41	3.036	759.1	2.307×10^{12}	5.799×10^{12}	3.544×10^{13}	9.400×10^{13}
0.3	0.05	0.09	0.015	42.4 ev	14.12	2.024	337.4	1.218×10^{13}	2.792×10^{13}	1.763×10^{14}	4.526×10^{14}
0.4	0.05	0.12	0.015	75.3 ev	18.83	1.518	189.8	4.048×10^{13}	8.228×10^{13}	5.432×10^{14}	1.334×10^{15}
0.5	0.05	0.15	0.015	117.7 ev	23.54	1.215	121.5	1.042×10^{14}	1.836×10^{14}	1.283×10^{15}	2.976×10^{15}
0.6	0.05	0.18	0.015	169.5 ev	28.24	1.012	84.3	2.273×10^{14}	3.413×10^{14}	2.554×10^{15}	5.533×10^{15}
0.7	0.05	0.21	0.015	230.6 ev	32.95	0.868	62.0	4.389×10^{14}	5.546×10^{14}	4.487×10^{15}	8.990×10^{15}
0.8	0.05	0.24	0.015	301.2 ev	37.66	0.759	47.4	7.732×10^{14}	8.155×10^{14}	7.203×10^{15}	1.322×10^{16}
0.9	0.05	0.27	0.015	381.3 ev	42.36	0.675	37.5	1.258×10^{15}	1.101×10^{15}	1.070×10^{16}	1.785×10^{16}
1.0	0.05	0.30	0.015	470.7 ev	47.07	0.607	30.4	1.918×10^{15}	1.386×10^{15}	1.495×10^{16}	2.247×10^{16}
1.2	0.10	0.36	0.030	678.0 ev	113	0.506	42.4	3.787×10^{15}	1.852×10^{15}	2.509×10^{16}	3.002×10^{16}
1.4	0.10	0.42	0.030	923.0 ev	132	0.434	31.0	6.194×10^{15}	2.041×10^{15}	3.552×10^{16}	3.309×10^{16}
1.6	0.10	0.48	0.030	1.21 kev	151	0.380	23.7	8.646×10^{15}	1.913×10^{15}	4.354×10^{16}	3.101×10^{16}
1.8	0.10	0.54	0.030	1.53 kev	170	0.337	18.7	1.047×10^{16}	1.554×10^{15}	4.697×10^{16}	2.519×10^{16}
2.0	0.10	0.60	0.030	1.88 kev	188	0.304	15.2	1.109×10^{16}	1.104×10^{15}	4.482×10^{16}	1.790×10^{16}
2.2	0.10	0.66	0.030	2.28 kev	207	0.276	12.5	1.051×10^{16}	7.015×10^{14}	3.861×10^{16}	1.137×10^{16}
2.4	0.10	0.72	0.030	2.71 kev	226	0.253	10.5	8.854×10^{15}	3.959×10^{14}	2.983×10^{16}	6.418×10^{15}
2.6	0.10	0.78	0.030	3.18 kev	245	0.233	8.98	6.665×10^{15}	1.999×10^{14}	2.072×10^{16}	3.240×10^{15}
2.8	0.10	0.84	0.030	3.69 kev	264	0.217	7.75	4.538×10^{15}	9.132×10^{13}	1.311×10^{16}	1.480×10^{15}
3.0	0.10	0.90	0.030	4.24 kev	282	0.203	6.75	2.799×10^{15}	3.757×10^{13}	7.541×10^{15}	6.090×10^{14}
3.2	0.10	0.96	0.030	4.82 kev	301	0.190	5.93	1.564×10^{15}	1.424×10^{13}	3.953×10^{15}	2.308×10^{14}
3.4	0.10	1.02	0.030	5.44 kev	320	0.179	5.26	7.932×10^{14}	5.033×10^{12}	1.887×10^{15}	8.159×10^{13}

TABLE 1

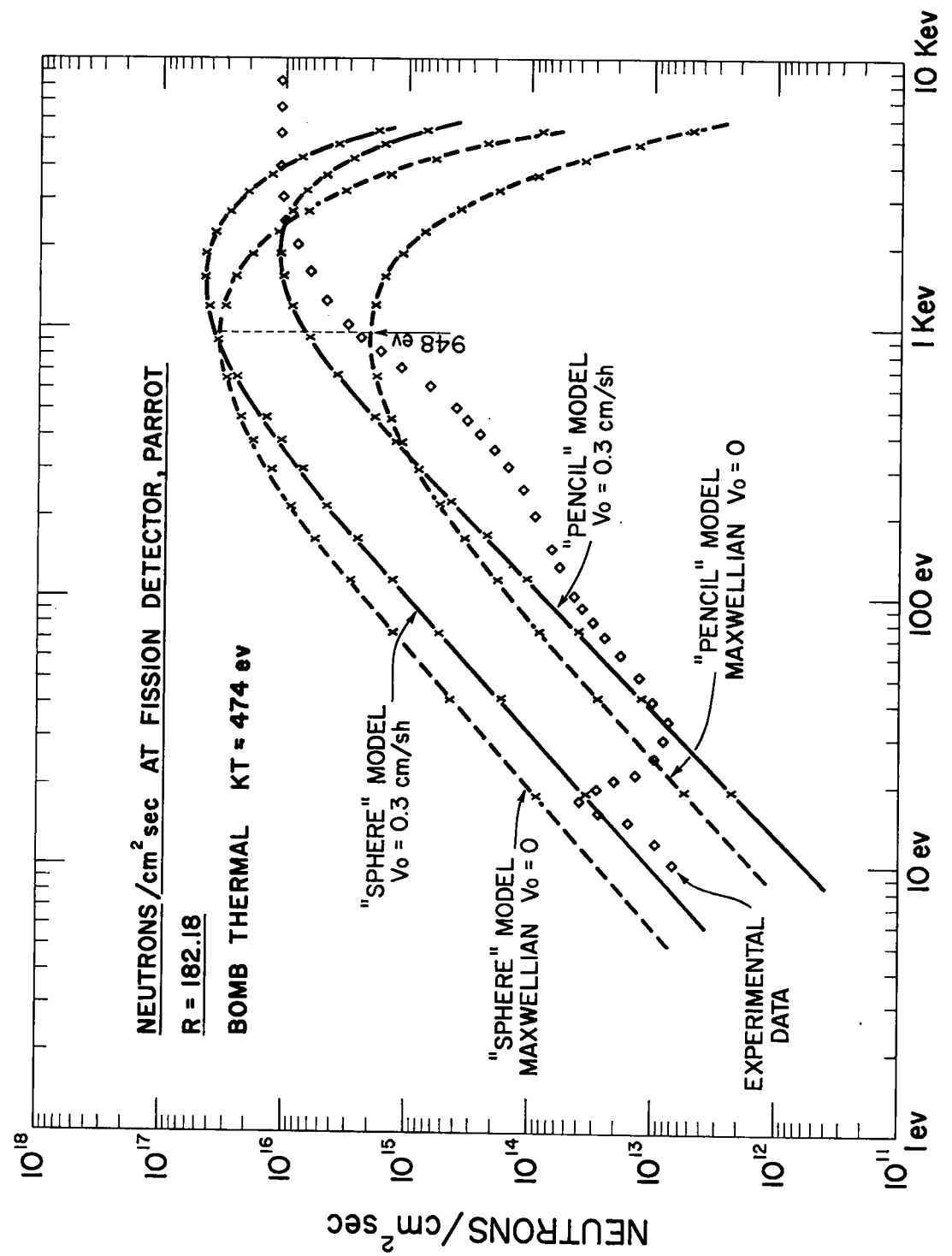


FIG. 6. THERMAL NEUTRON SPECTRA. BOMB THERMAL KT = 474 ev.

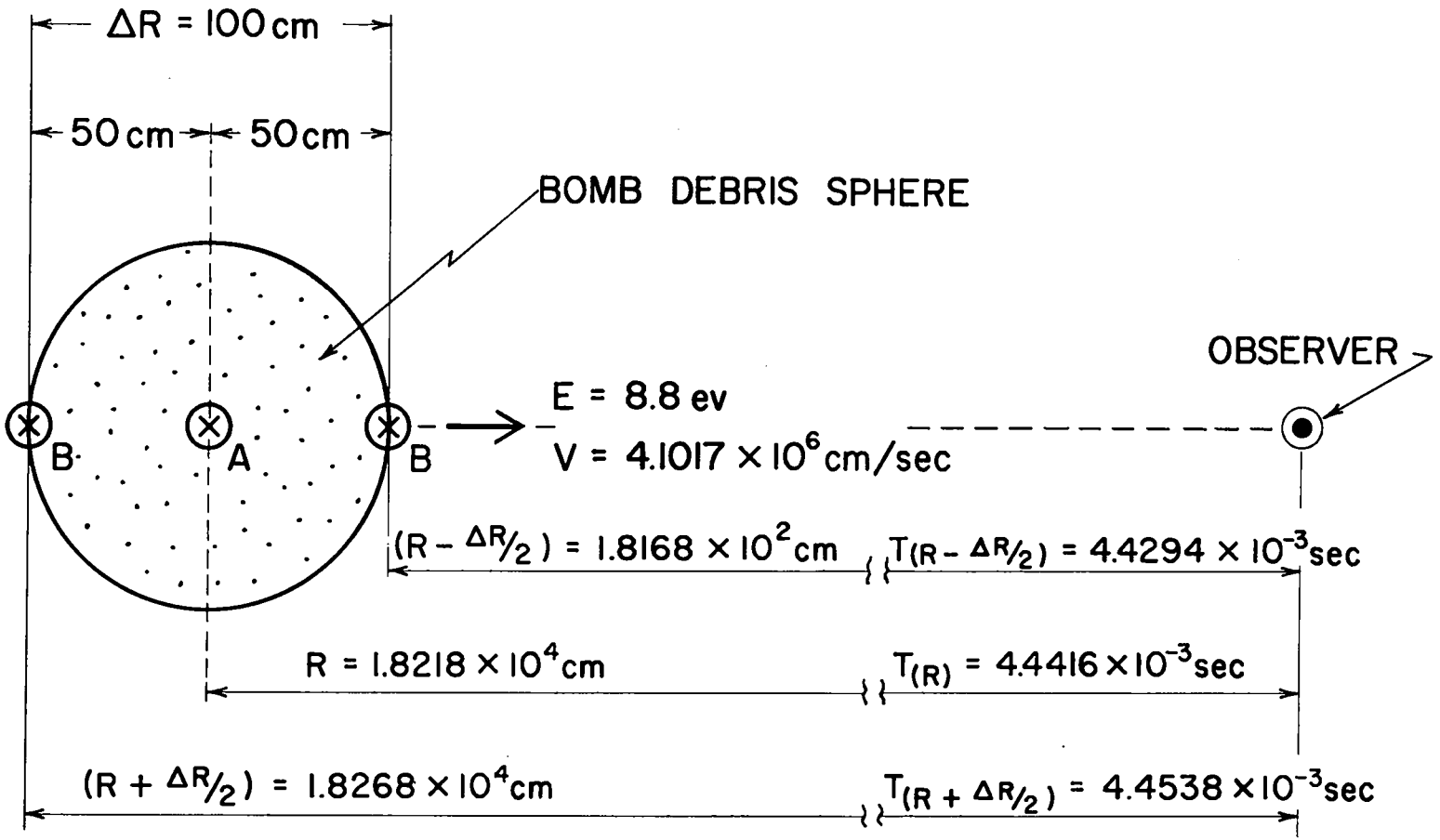


FIG. 7. MODEL A AND B FOR NEUTRON SOURCE IN DEBRIS SPHERE.

LA-UR- 11-04083

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distribution is unlimited.

Title:	Nuclear Weapons Fundamentals
Author(s):	James Bradley Beck
Intended for:	PONI (Project on Nuclear Issues) Presentation to Staff Washington, DC July 20, 2011

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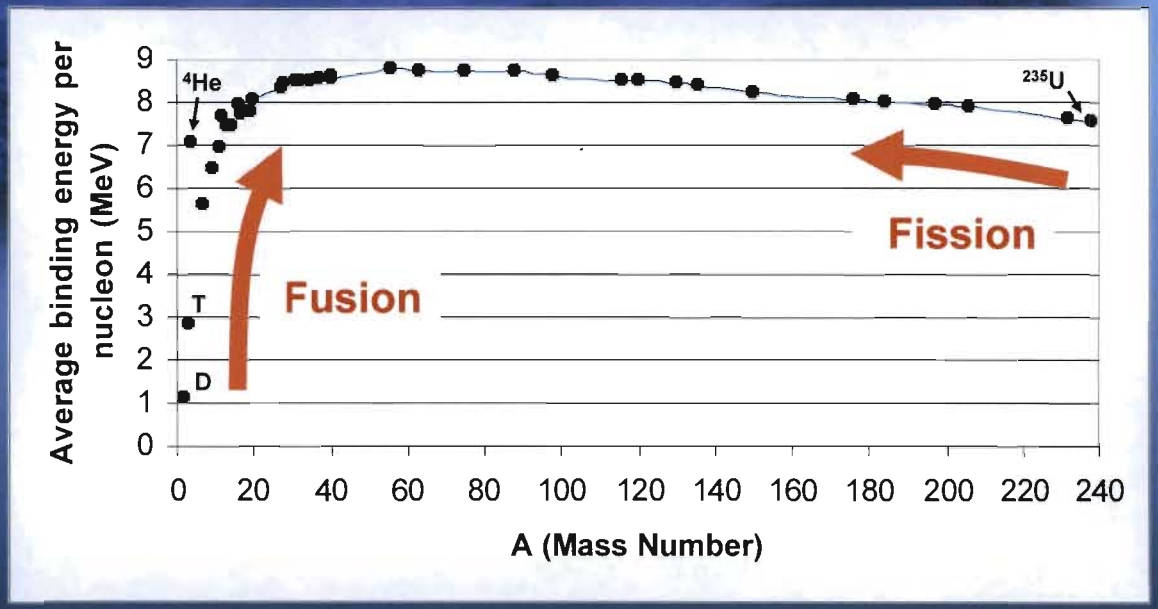
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Form 836 (7/06)

Binding Energy

Fundamental Law:
The rearrangement of a system to a more tightly bound state results in the release of energy

Energy released is equal to the change in binding energy



An example, fission energy release:

$^{235}U + n \rightarrow {}^{236}U \rightarrow$ 2 Fission Fragments + 2n

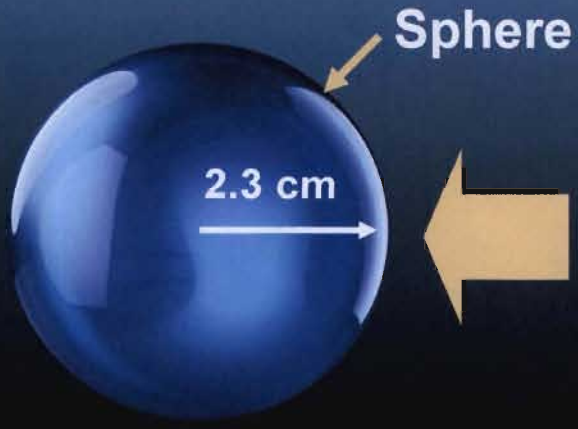
Mass (235U + n): 1996.0 MeV

Mass (after Fission): 1793.6 MeV

Change in B.E. = 202.4 MeV per fission

Comparative Energy Release

	Energy/Reaction	Energy density*
Combustion (Chemical)	4 eV	4.1×10^4 J/cm^3
Fission	200 MeV	1.5×10^{12} J/cm^3



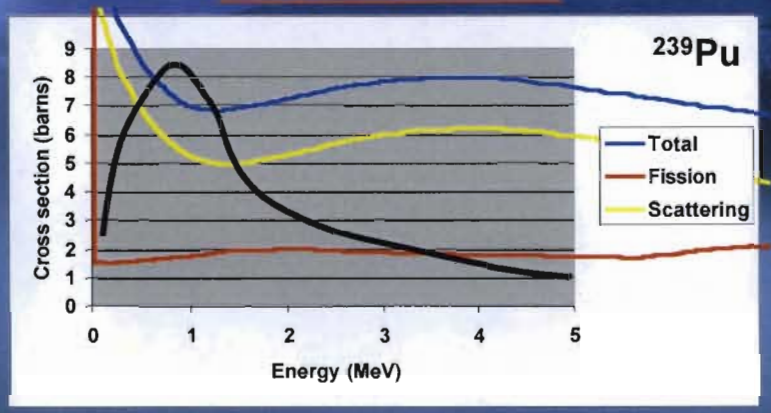
	Energy Available*	100 Watt (J/s) bulb would burn for:
72 g coal	2.2×10^6 J (~1 lb. TNT)	~6 hours
or		
1 kg U	80×10^{12} J (19 kt TNT)	~25,370 years

* Complete combustion or fission is assumed

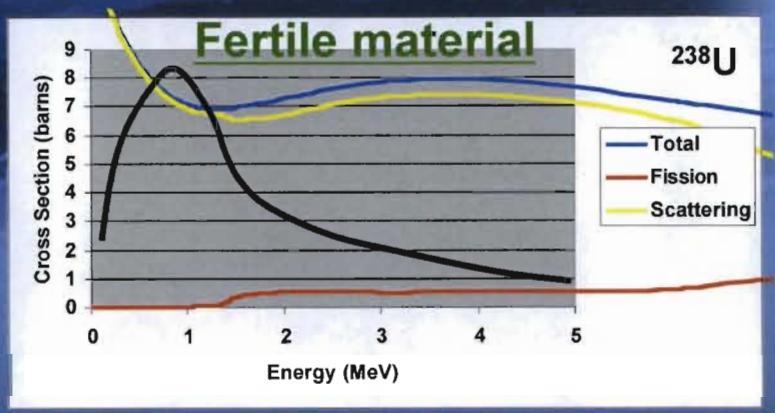
Neutron Cross Sections

(related to probability of reaction)

Fissile material

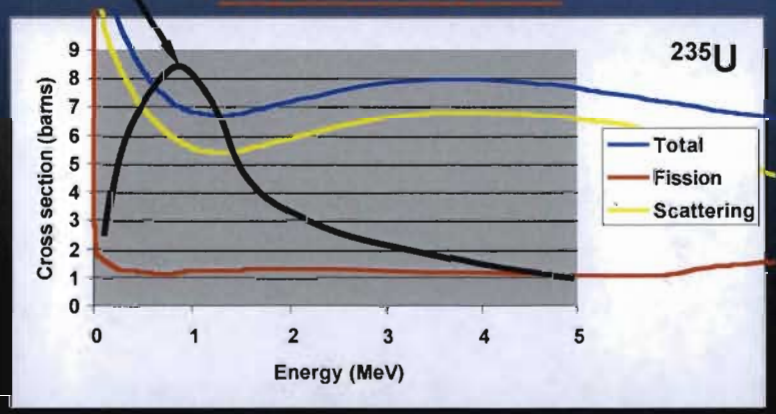


Fertile material

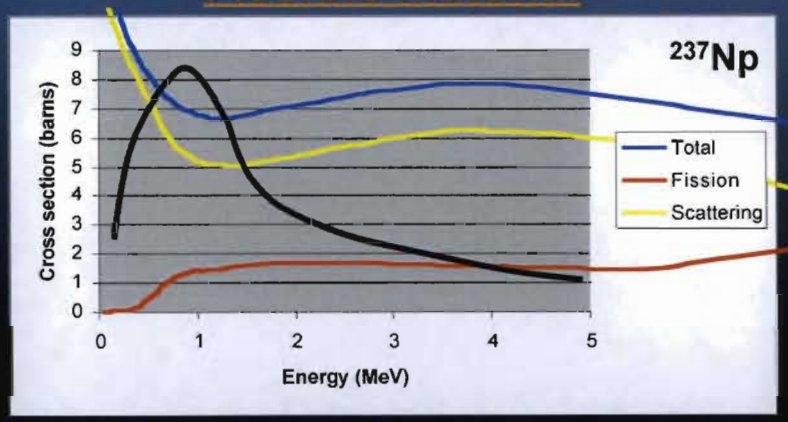


Fission neutron spectrum

Fissile material



Fissible material



1 barn = 10^{-24} cm^2

Factors Affecting Critical Mass

Critical mass – amount of material needed to just sustain a fission chain reaction (and constant neutron population)

Material - ^{239}Pu has a smaller critical mass compared with ^{235}U

Bare sphere critical mass



^{235}U
52 kg

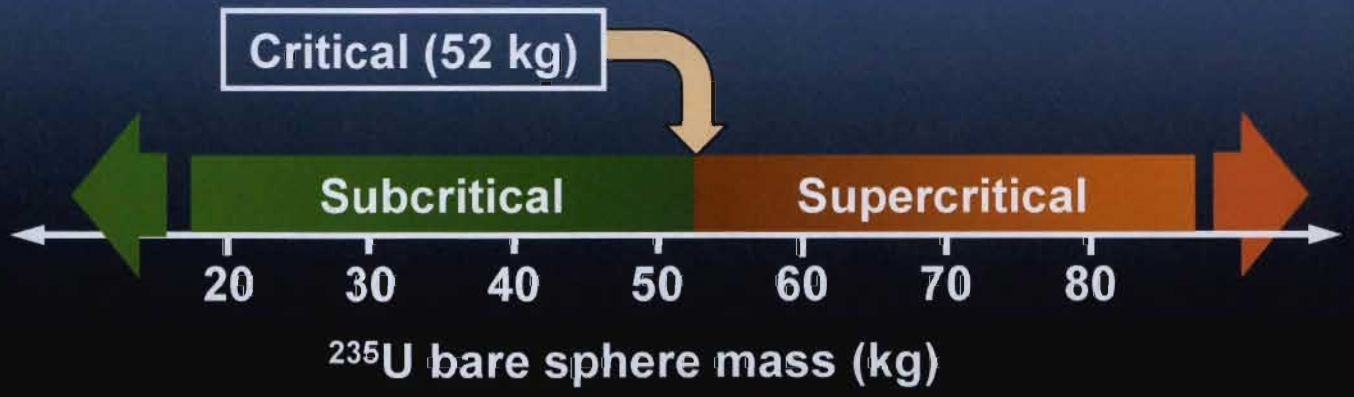


^{239}Pu
10.5 kg

* Colors not indicative of true material

Factors Affecting Critical Mass (Cont.)

Mass – for a given shape and density, a larger mass of material has a higher criticality



Factors Affecting Critical Mass (Cont.)

Compression – increases in material density result in smaller critical mass

Bare sphere ^{235}U critical mass



Factors Affecting Critical Mass (Cont.)

Surroundings – surrounding a system by a strong neutron reflector results in a reduced critical mass



Explosive Fissionable Material

- Any material that can be assembled into a supercritical mass, supporting a fast neutron chain reaction
  - » Weapon-grade materials
    - highly enriched uranium, >93% ^{235}U
    - weapons-grade Pu, ^{239}Pu with 6% ^{240}Pu
  - » Alternatives
    - ^{233}U
    - reactor-grade Pu
    - uranium with < 93% ^{235}U
    - fissible isotope ^{237}Np (neptunium)



Plutonium



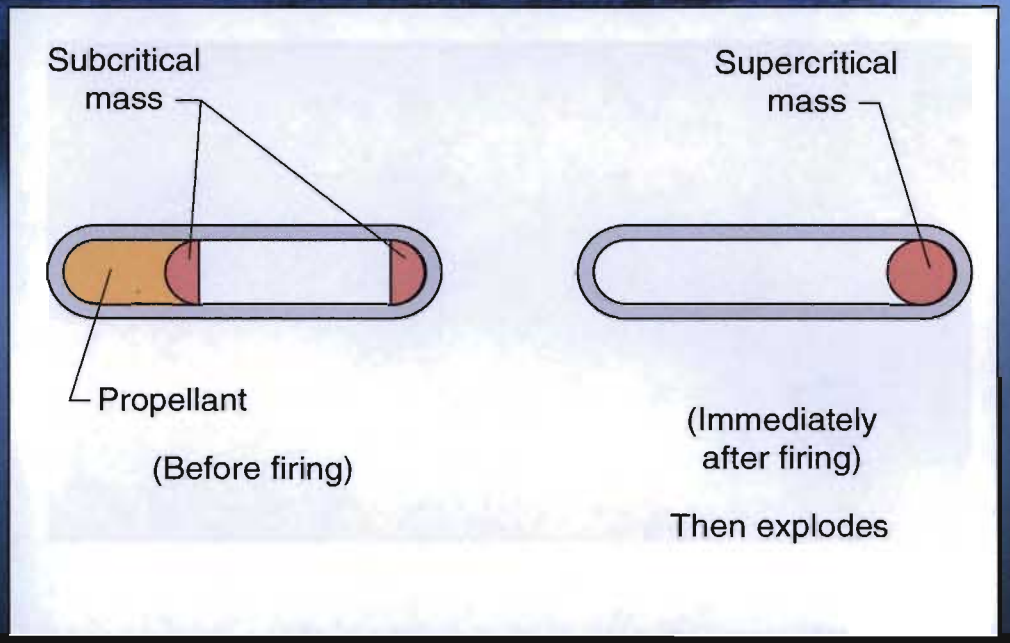
- Essential material to make a nuclear weapon
  - » 25 kg ^{235}U or 4 kg Pu can be enough

Fission Weapons

- A system for rapidly transforming a mass of 'explosive fissionable material' from a subcritical configuration to a highly supercritical configuration
- Initiation of a runaway neutron chain reaction while in supercritical configuration
- Maintain supercritical configuration long enough to allow large fission energy release

Gun Assembly

- Simple design
- Assemble subcritical masses together into a supercritical mass using propellant
- Inefficient use of material
- Slow assembly time necessitates use of a material with a very low neutron background (e.g., ^{235}U) to avoid pre-initiation; plutonium is precluded



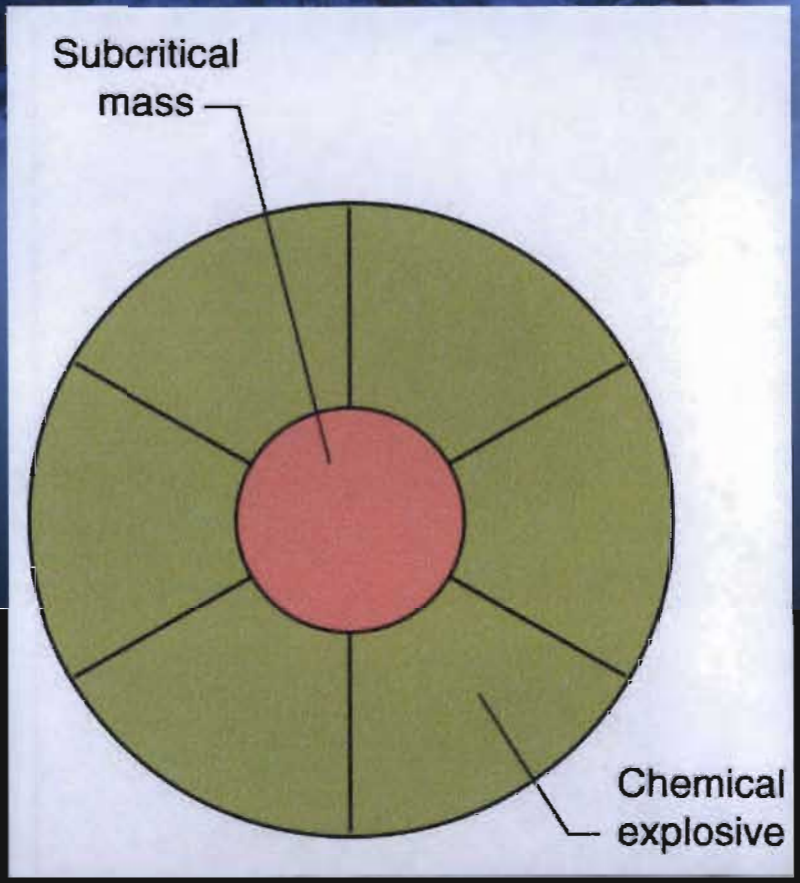
Compare:
HEU : ~1 neutron/kg/second
WGPu : ~60,000 neutrons/kg/second

Ivy/King – tested on 11/15/52 at Enewetak; largest US fission only device (500 kt)

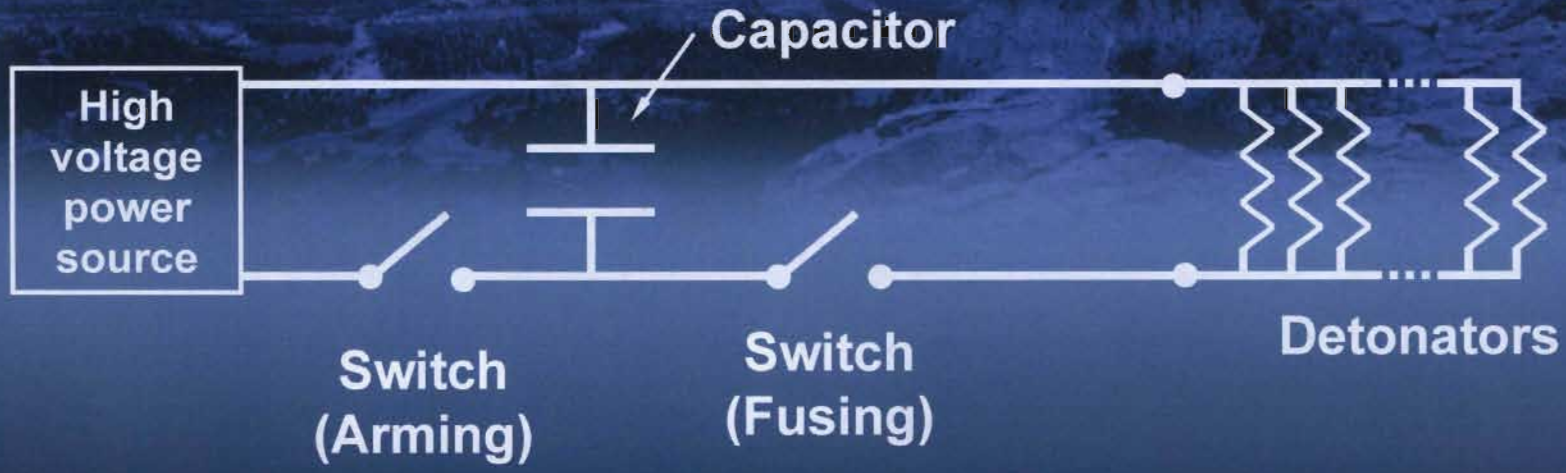


Implosion Assembly – before firing

- Must symmetrically initiate outer surface of high explosive charge
  - » Firing system
  - » High explosive lenses



Simplified Firing System



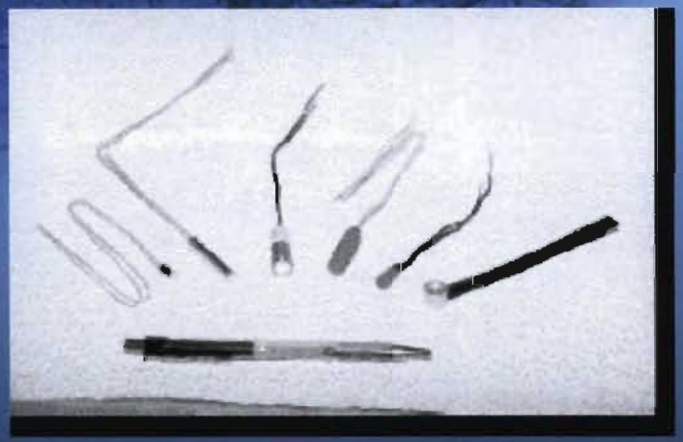
- Arming signal closes switch resulting in slow charging of capacitor
- Fusing signal closes "fast" switch, rapidly delivering stored capacitor energy to detonators

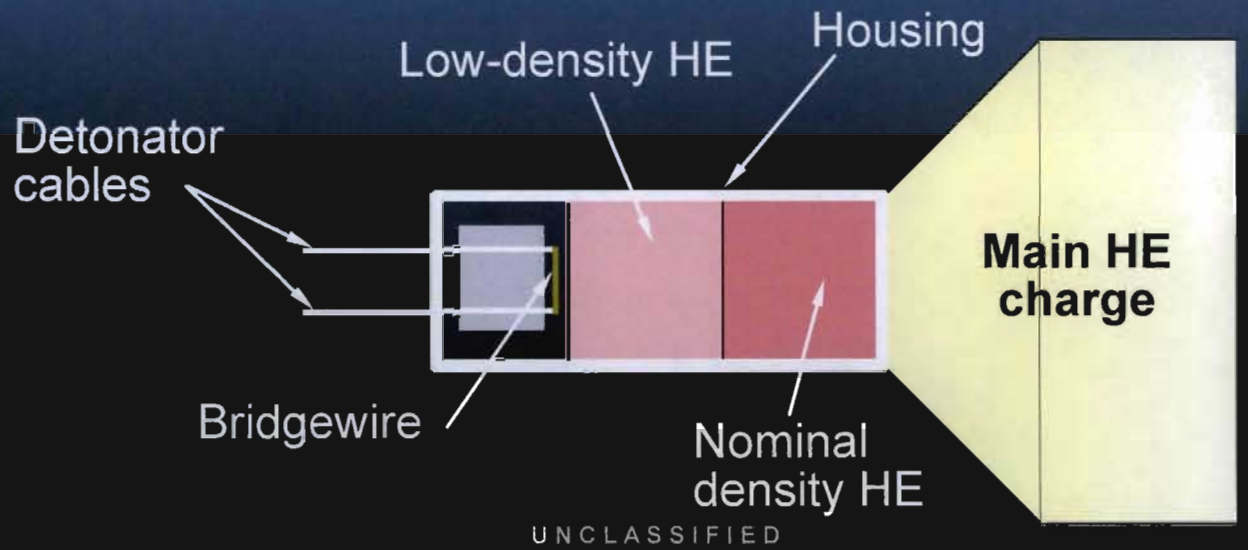
Detonators

- Used to initiate larger high explosive charges
- Convert electrical power into high explosive detonation
- Repeatability must be within small fraction of a second

Exploding Bridgewire (EBW) Detonators

- Large pulse of electric current vaporizes thin bridgewire, producing shock wave
- Shock wave initiates adjacent low-density HE pellet
- Detonation propagates thru HE pellets, strengthening in nominal density HE
- Initiation of main HE charge follows





High Explosives (HE)

- Castable
  - » TNT (trinitrotoluene)
  - » Composition B-3 (60% RDX, 40% TNT)
- Plastic-bonded
  - » mostly HMX or RDX based
  - » hydrostatic or isostatic press
- Final machining required for both types

HE melting kettle



Hydrostatic press



Pit Fabrication

Explosive Fissionable Material

Melting & Casting

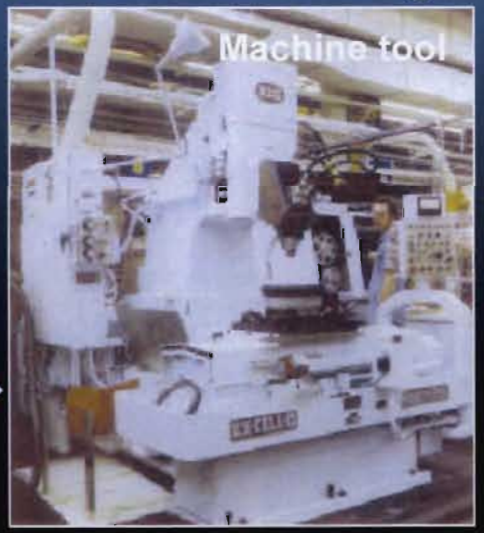


Billet

Cast Part

Rolled & Hydroformed

Finish machining



Inspection

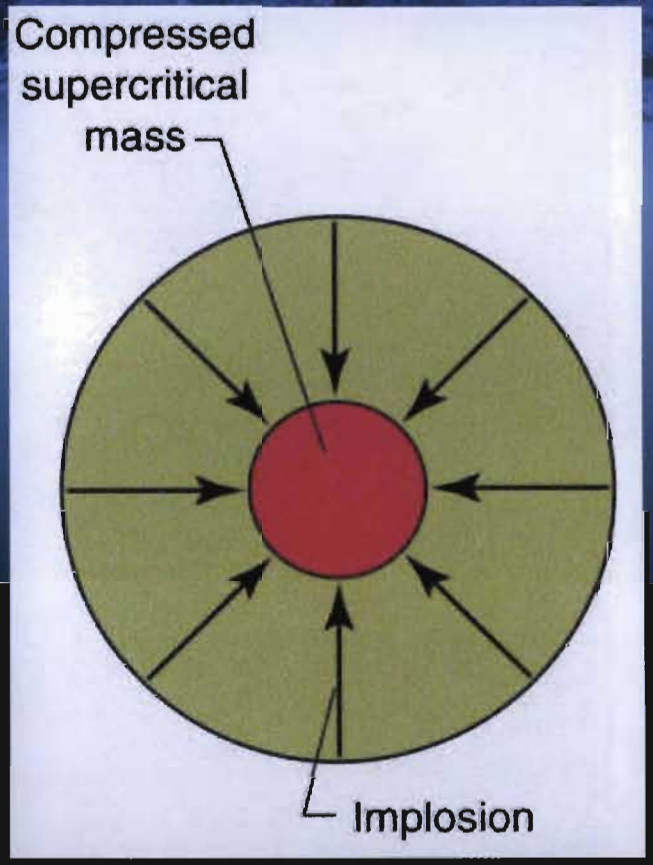
Final Part

Note: Plutonium operations performed in glovebox



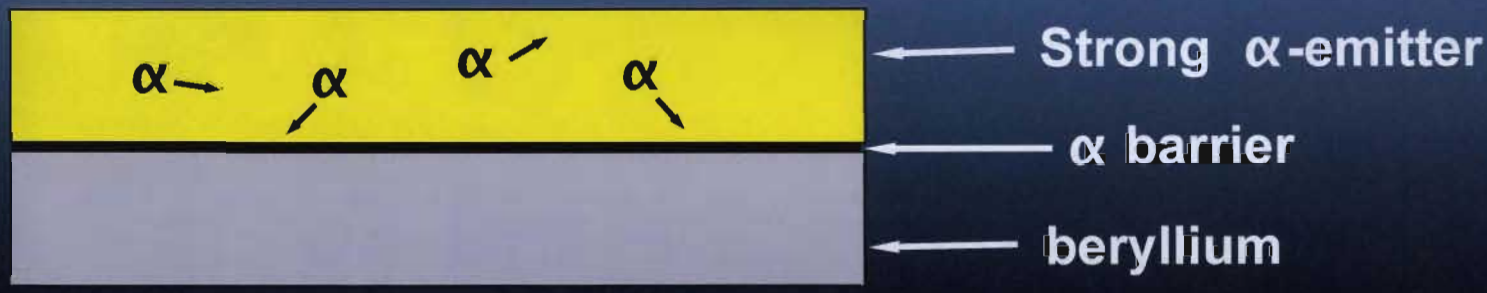
Implosion Assembly – after firing

- Following implosion, pit will reach a point of maximum supercriticality
- At this time, neutrons must be introduced into pit to begin fission chain reaction (this is called neutron initiation)
  - » Internal initiators
  - » External initiators



Internal Neutron Initiators

(α,n) Initiator – based on the reaction in which α particles from a radioactive isotope (e.g., polonium-210) interact with a light element (e.g., beryllium), thereby releasing neutrons

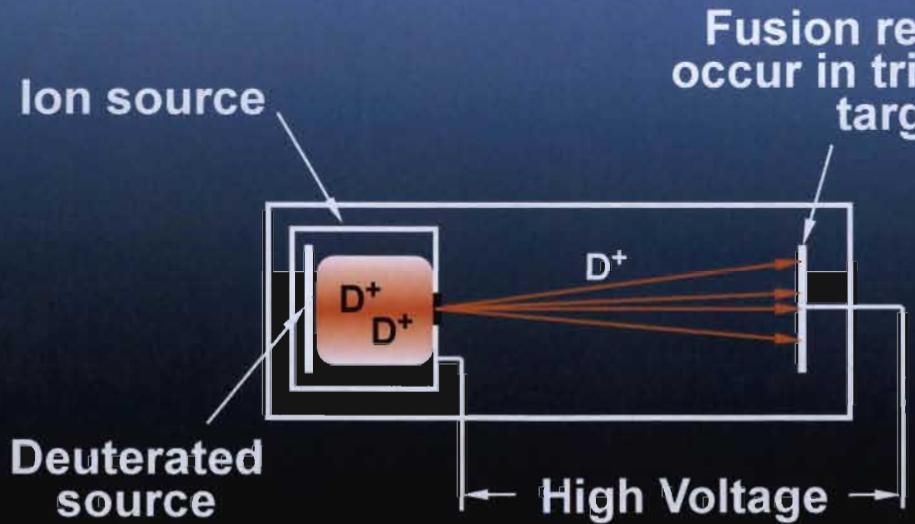


$$^{210}_{84}Po \rightarrow {}^{206}_{82}Pb + \alpha(^{4}_{2}He) \rightarrow \alpha + {}^{9}_{4}Be \rightarrow {}^{12}_{6}C + n$$

External Neutron Initiators

Neutron generator tube - based on fusion of deuterium and tritium produced in a small accelerator



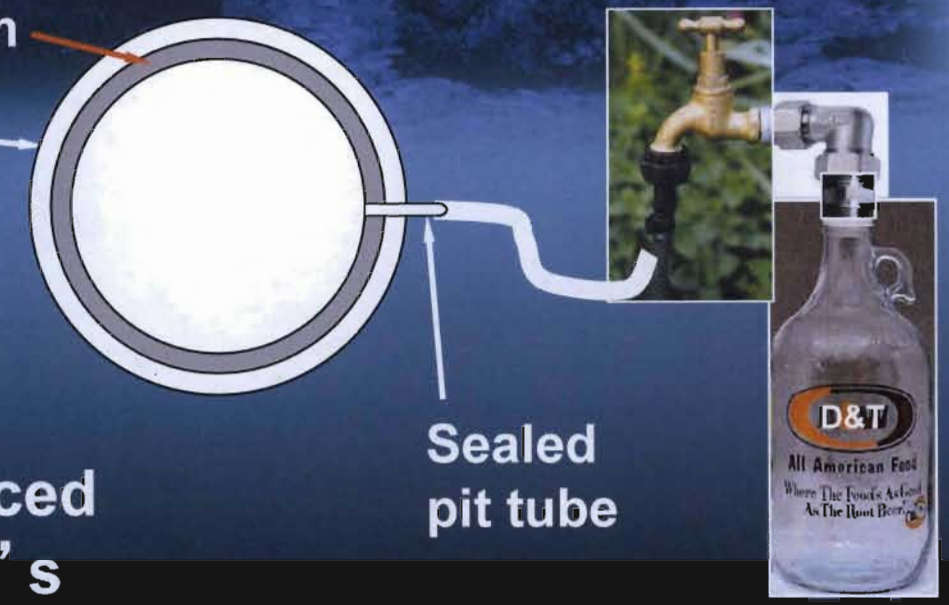


Note: tritium is radioactive and must be replenished

Boosted Fission Weapons

- Fusion produces energetic neutrons which cause further fission. This is called *boosting*.
- Boosting is used in primaries of thermonuclear weapons and can also be used in fission only weapons.

Boosted Fission Weapons (Cont.)



1. Mixture of deuterium and tritium (boost gas) is introduced from a reservoir to pit's central cavity
2. During implosion, boost gas is compressed along with the fissile material

Boosted Fission Weapons (Cont.)

3. Driven by energy from fission, D-T fusion occurs, flooding compressed pit with high energy neutrons
4. These neutrons produce additional fissions, driving nuclear yield to much higher values

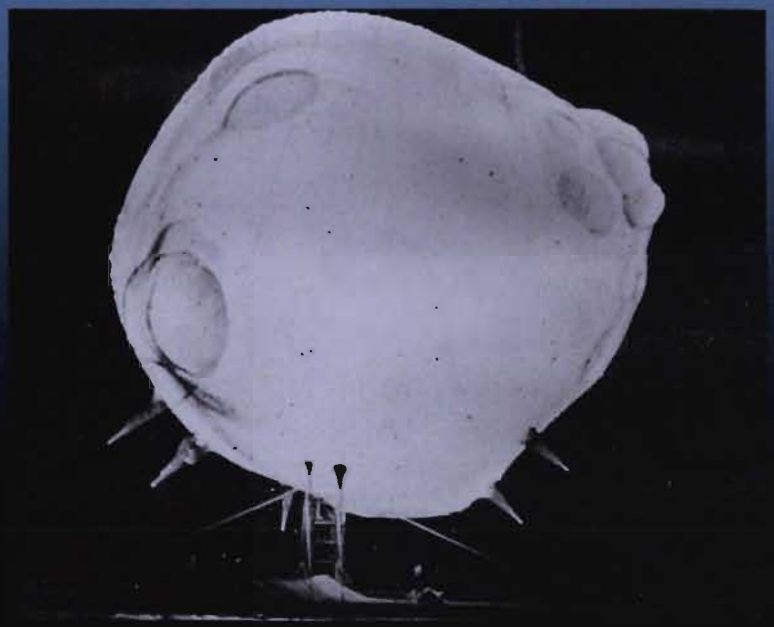
Note: Bulk of the yield is from fission; thermonuclear fusion yield is a few percent of the total

Greenhouse/Item – tested on 5/24/51 at Enewetak
First US boosted device (45.5 kt)









Additional Nuclear Physics

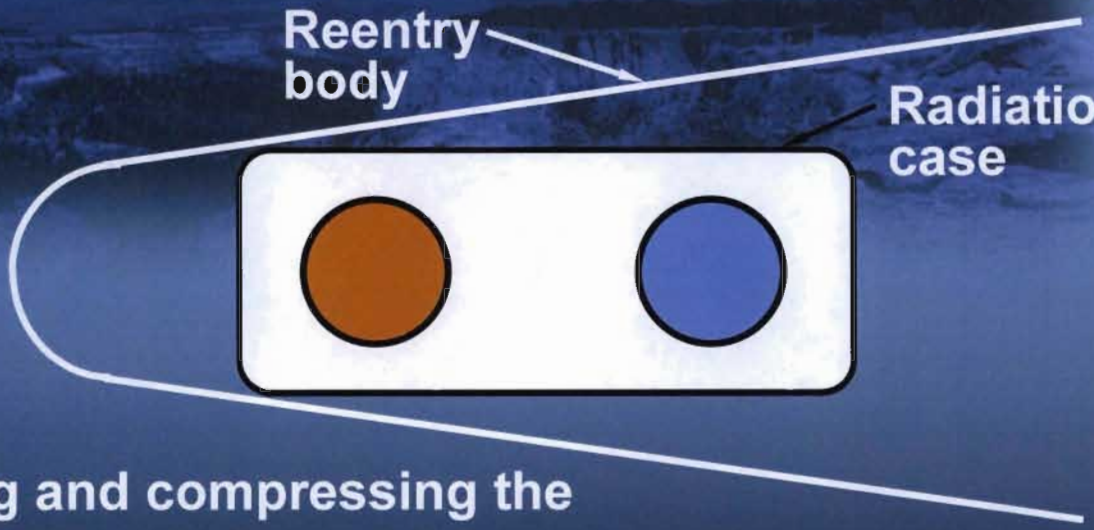
- Isotopes of lithium absorb neutrons resulting in the production of tritium

$$^{6}_{3}\mathrm{Li} + n \rightarrow T + {}^{4}_{2}\mathrm{He} + 4.8\ \mathrm{MeV}$$

$$^{7}_{3}\mathrm{Li} + n \rightarrow T + {}^{4}_{2}\mathrm{He} + n - 2.5\ \mathrm{MeV}$$

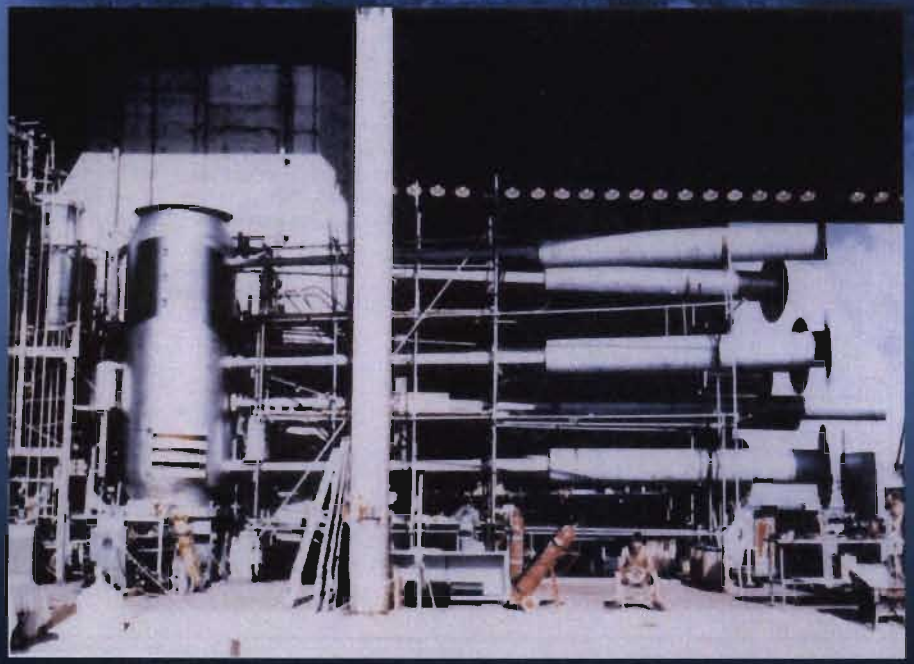
- Tritium can undergo subsequent fusion with deuterium
- Unlike tritium, lithium is a stable compound

Thermonuclear Weapons



- Radiation energy produced by primary stage is contained by radiation case
- X-ray energy flows toward and around the secondary stage heating and compressing the thermonuclear fuel (e.g., lithium deuteride)
- While thermonuclear fuel is undergoing heating and compression, neutrons are interacting with lithium, creating tritium
- Tritium and deuterium subsequently undergo fusion producing high-energy neutrons, producing additional fissions and tritium

Ivy/Mike – tested on 10/31/52 at Enewetak/Elugelab; 10.4 Mt





- "Experimental" thermonuclear device
- TN fuel was liquid deuterium
- Complex and bulky cryogenic equipment

Castle/Bravo - tested on 2/28/54 at Bikini; Largest US detonation at 15 Mt

- Used lithium deuteride as a thermonuclear fuel

"Why buy a cow when powdered milk is so cheap?"

Harold Agnew, South Pacific (~1952-1954)



Largest Weapon Detonation

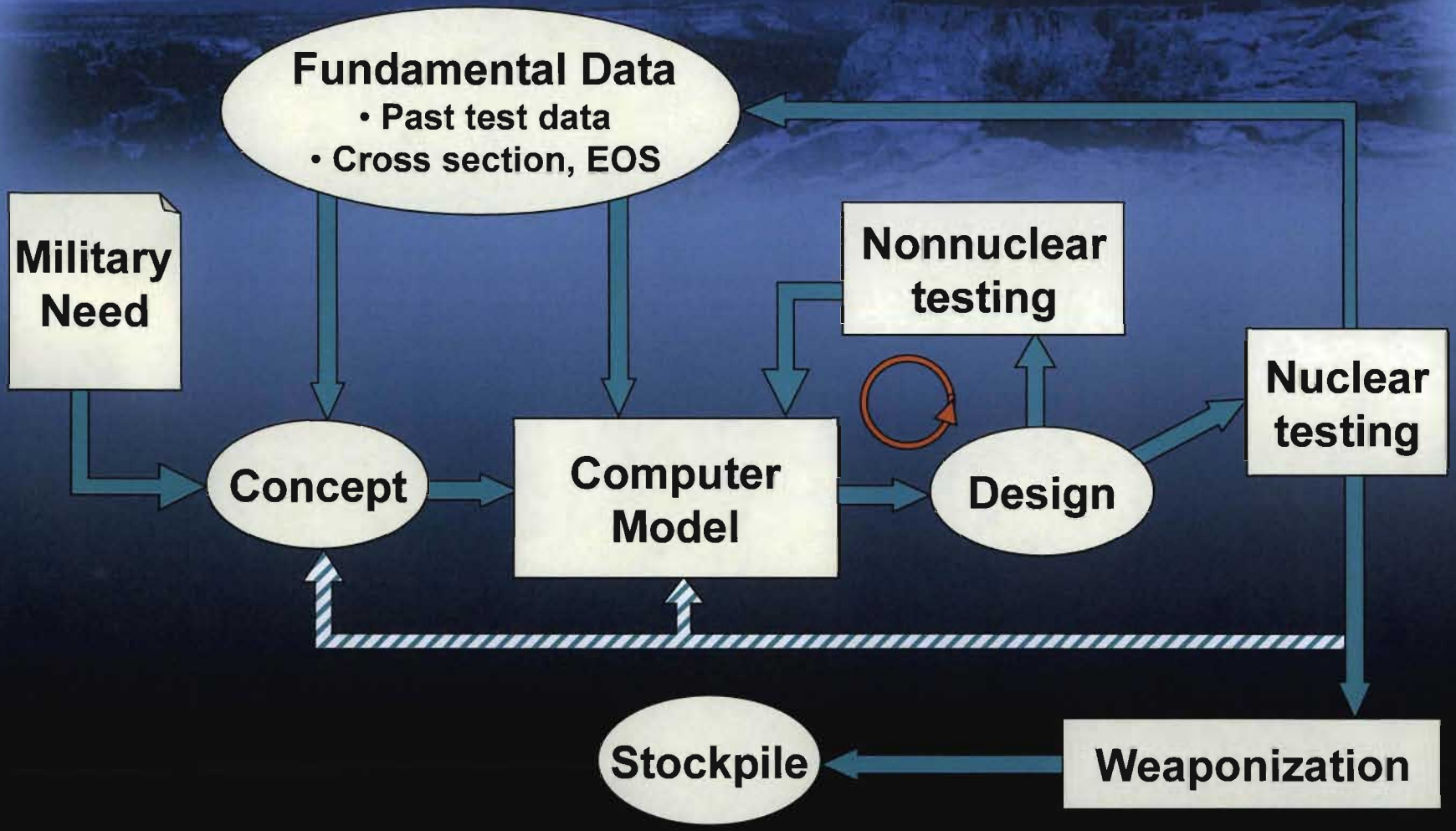
- Soviet test at Novaja Zemlya on 30 October 1961
- Fired at: ~58 Mt
- Design yield: 100 Mt



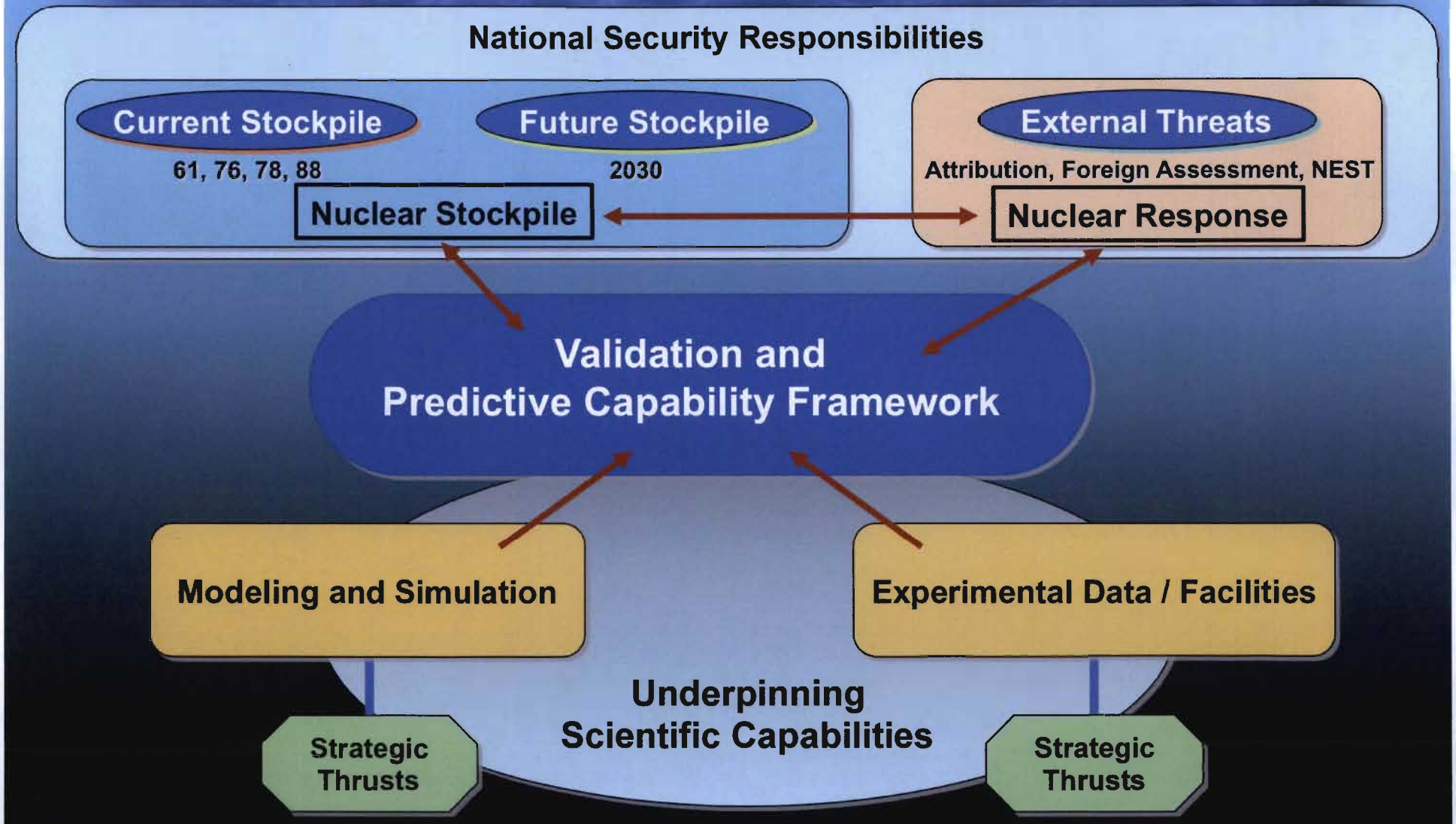


Dr. Edward Teller (5' 8")
at Snezhinsk (C-70)

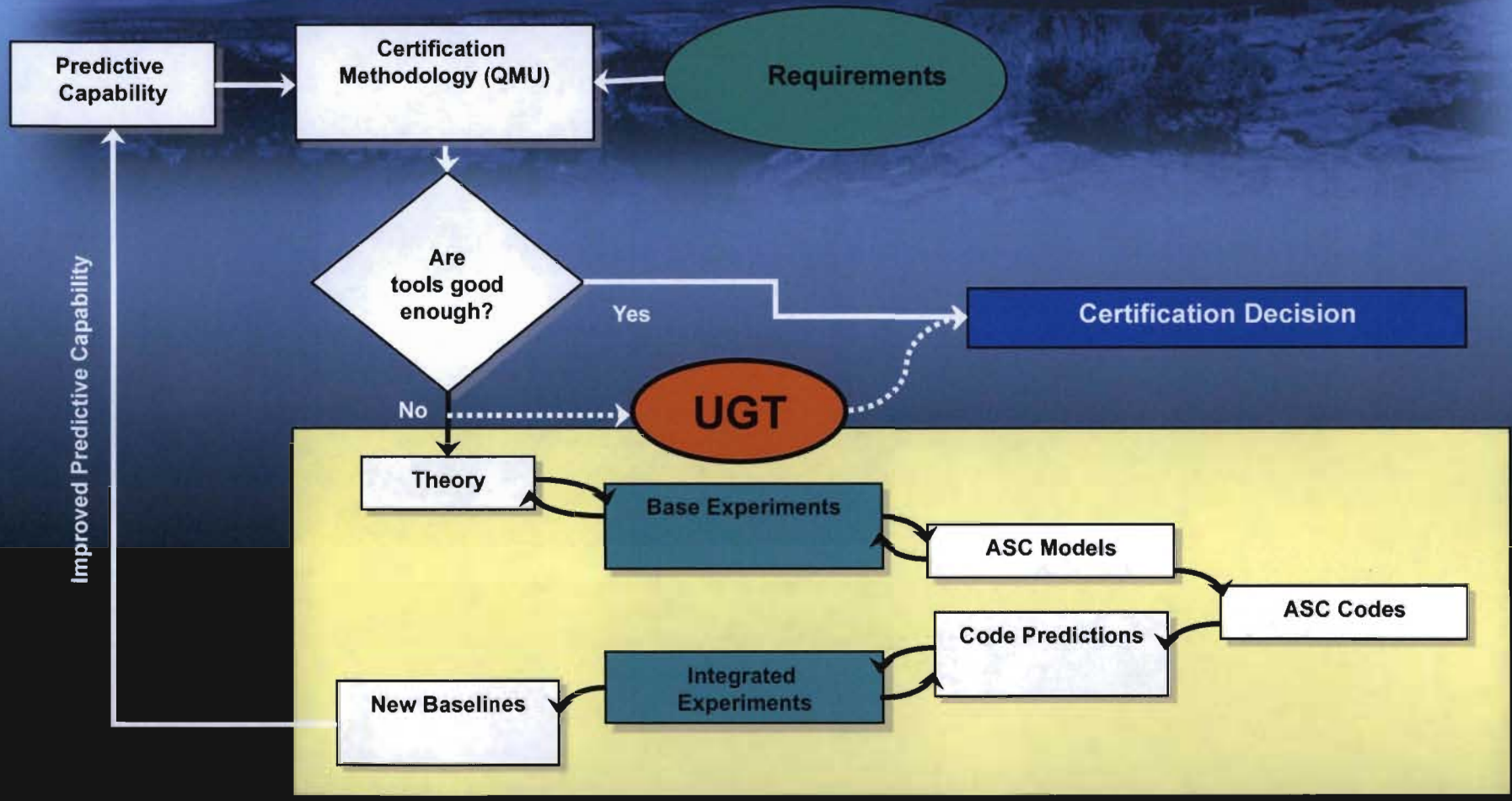
Traditional Design and Development



We will meet our National Security responsibilities through Validated Predictive Capability

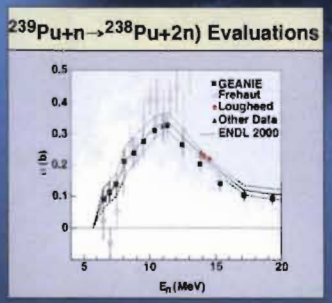


How does predictive capability fit in the big picture?

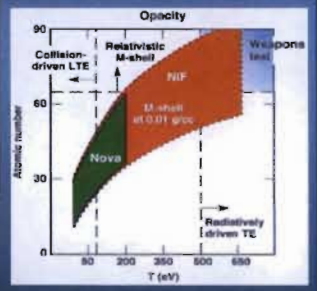


Range of Length Scales
From the size of the nucleus to the size of the weapon

Nuclear Structure♪



Atoms♪



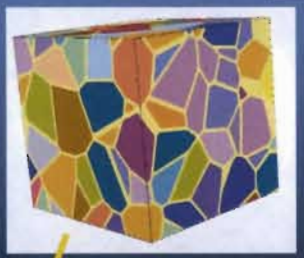
Molecules♪ and Shocks♪



Materials Strengths♪



High Explosive♪ Constitutive Models



Full System♪



10^{-15} 10^{-12} 10^{-9} 10^{-6} 10^{-3} 1

Characteristic Length Scale (m)

Nonnuclear Testing

- Instrumented HE tests, possibly including mock fissile material (hydrotest)
  - » Characterize detonators, HE, and firing set
  - » HE system performance and pit behavior
  - » Gas cavity formation
  - » Radiation case dynamics

Pin Diagnostics

- Measure implosion velocity and symmetry
- Pins produce signals when struck by moving material
  - » Electrical
  - » Optical
  - » ~500 pins typical



Pin dome

- Oscilloscopes capture timing of signals



Oscilloscope

High-Speed Photography

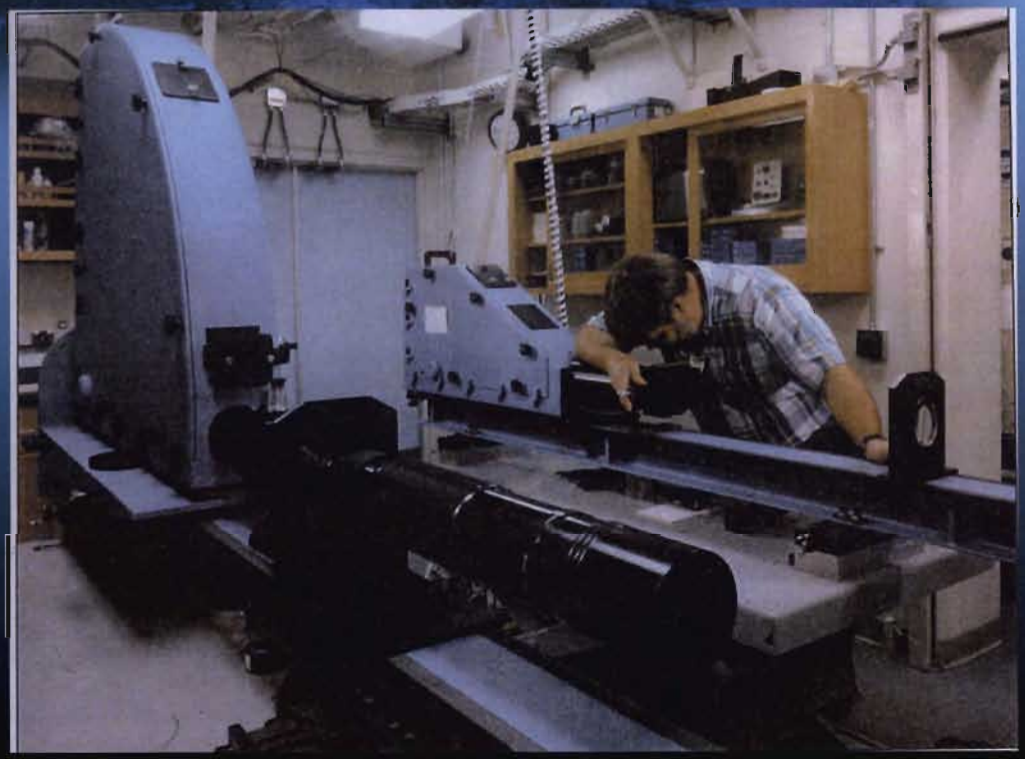
- Image high-speed events
  - » HE detonation waves (7-9 km/s)
  - » HE-driven plates (1-6 km/s)
- Used for the development of HE components and initiation systems
- Film and electronic cameras are used

High-Speed Photography (Cont.)

Rotating mirror cameras

Framing camera (left)
Streak camera (right)





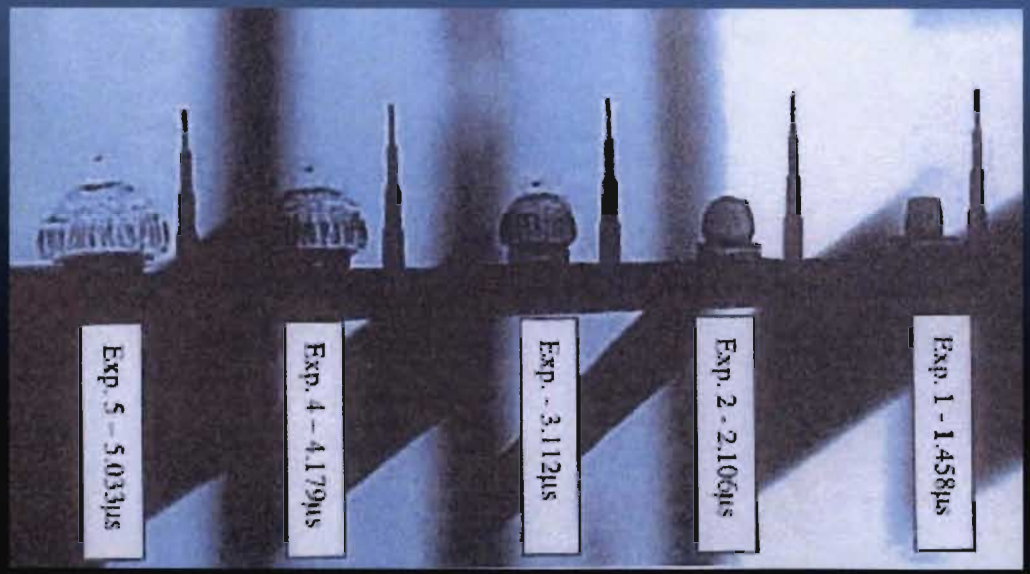
Inside a rotating mirror framing camera

High-Speed Photography (Cont.)

Rotating mirror framing camera images of exploding hand granade (~1 million frames per second)

Courtesy of David J. Fisher and Rodney L. Robbs, Naval Weapons Center, China Lake, CA. Official US Navy photographs.





Electronic framing camera images of exploding detonator

DARHT provides experimental data on the health of the deterrent

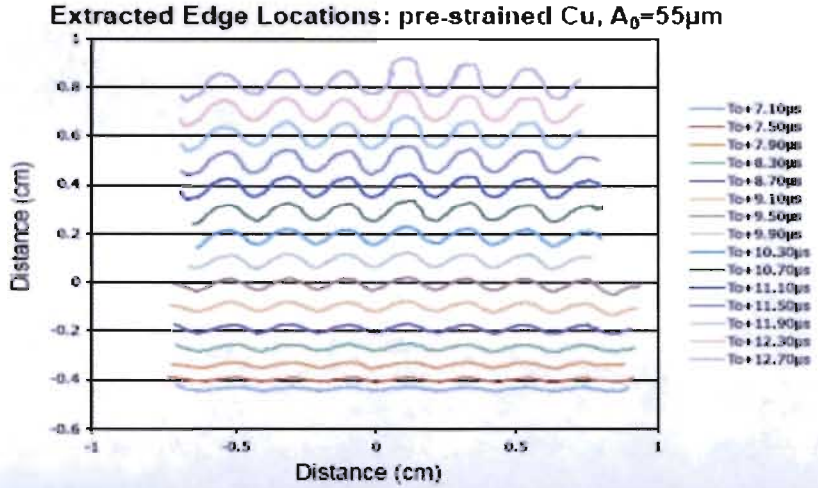
- World class X-ray radiography for hydrodynamic tests to gather data to support stockpile
- Axis 1 single image, operational since 1999
- Axis 2 up to four images
- World's first dual axis experiment successfully executed December 2009
- Experiments fully contained to reduce environmental impacts and increase shot rate

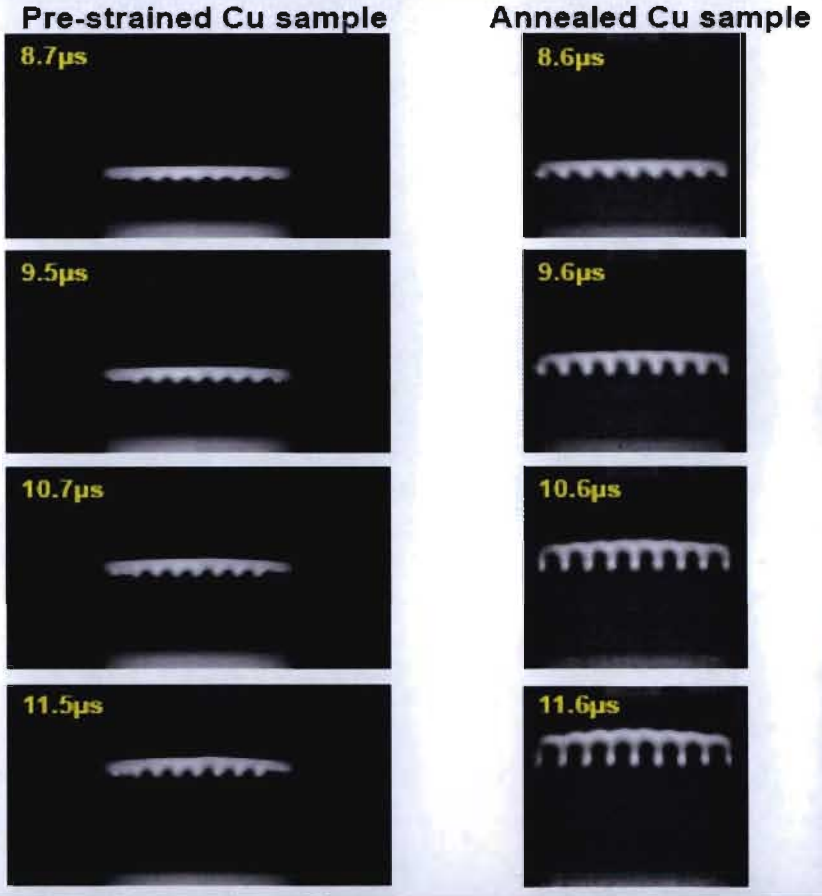



DARHT Containment System

pRad studies of perturbation growth rates as a function of time demonstrate a strong influence of materials processing

- **Comparison between fully annealed and cold worked copper samples.**
  - 55μm sinusoidal initial perturbation imposed on each sample.
  - Identical sample acceleration.
- **Significant reduction in growth rate is observed for cold worked Cu samples.**





Computer Codes

- *Computational Models* – sets of equations describing various weapons phenomenology and numerical solution techniques
  - » Radiation/Hydrodynamics
  - » Neutronics
  - » Thermonuclear burn
- *Physical Data* – unique for each material
  - » Neutron cross sections
  - » Equation of state
  - » Opacities
- *Nuclear test data* – needed to overcome our lack of full physics understanding (phenomenology and data)

Computers, Codes, and Nuclear Testing

- Manhattan Project work relied heavily on experimental and analytical programs – hand computing and electromechanical machines used
  - » produced workable unsophisticated designs (heavy, inefficient use of nuclear material)
  - » nuclear test of gun-assembled weapon not performed prior to dropping Little Boy
  - » if enough enriched uranium is available, gun designs are relatively easy

Computers, Codes, and Nuclear Testing (Cont.)

- Supercomputers and complex codes are used to make weapons lighter, smaller, safer, more efficient
  - » Classified nuclear test data essential to process (still lack understanding of full physics)
  - » US stockpile was designed with "supercomputers" equivalent to today's desktop PCs

Computers, Codes, and Nuclear Testing (Cont.)

- Advanced weapon states will continue to pursue larger computers to further understand weapon physics and operation
- Understanding stockpile aging issues without nuclear testing will require massive computational resources; success is not assured
- Supercomputers are of little value to beginning proliferants lacking nuclear test data

Nuclear Weapon Design is Unique

- Range of operating conditions within a nuclear weapon is greater than in anything else, manmade or natural, existing on earth
- Processes are very complicated and occur in extremely harsh environments
  - » extreme temperatures (>100 million degrees)
  - » high material velocities (>1 million miles/hour)
  - » very high pressures (>10 million atmospheres)
  - » small time scales (measured in billionths of a second)

Nuclear Weapon Design is Unique (Cont.)

- Forces are so large that the strongest metals compress and flow like fluids.
- Designing a machine that by its very nature destroys itself in a fraction of a second (and everything within a kilometer or more over the next several seconds) obviously complicates the process of understanding its reliability and of refining the design.
- Some parts of the device will be vaporized in an explosion while other parts only a few centimeters away must remain intact and function under the harsh environmental conditions described.

Annual Assessment– A statutory requirement and the highest priority of the Lab Director

- Detailed reports are prepared by lab staff on each warhead
- Lab Director briefed in detail by staff
- Lab Director issues letter to Secretaries of Defense & Energy and Chair of the NWC
- Lab Director briefs the Secretary of Energy
- STRATCOM prepares separate report and briefs the Secretary of Defense
- Secretaries of Defense & Energy brief the President
- President advises Congress











Key Questions for a Capability-Based Deterrent

- How agile do we need to be?
  - 3 – 5 – 10 years?
- How do we assess this?
  - historic weapon development times?
  - expert assessment?
  - negotiated via arms control?
- What about military readiness?
  - Dual use delivery platforms?
  - Dedicated platforms?
- How will capability be perceived by –
  - Allies? Adversaries? The rest of the world?
  - Must linkage to stockpile goals and a CTBT be explicit?
  - Will transparency play an important role?
  - Do we design transparency into weapons? The complex?

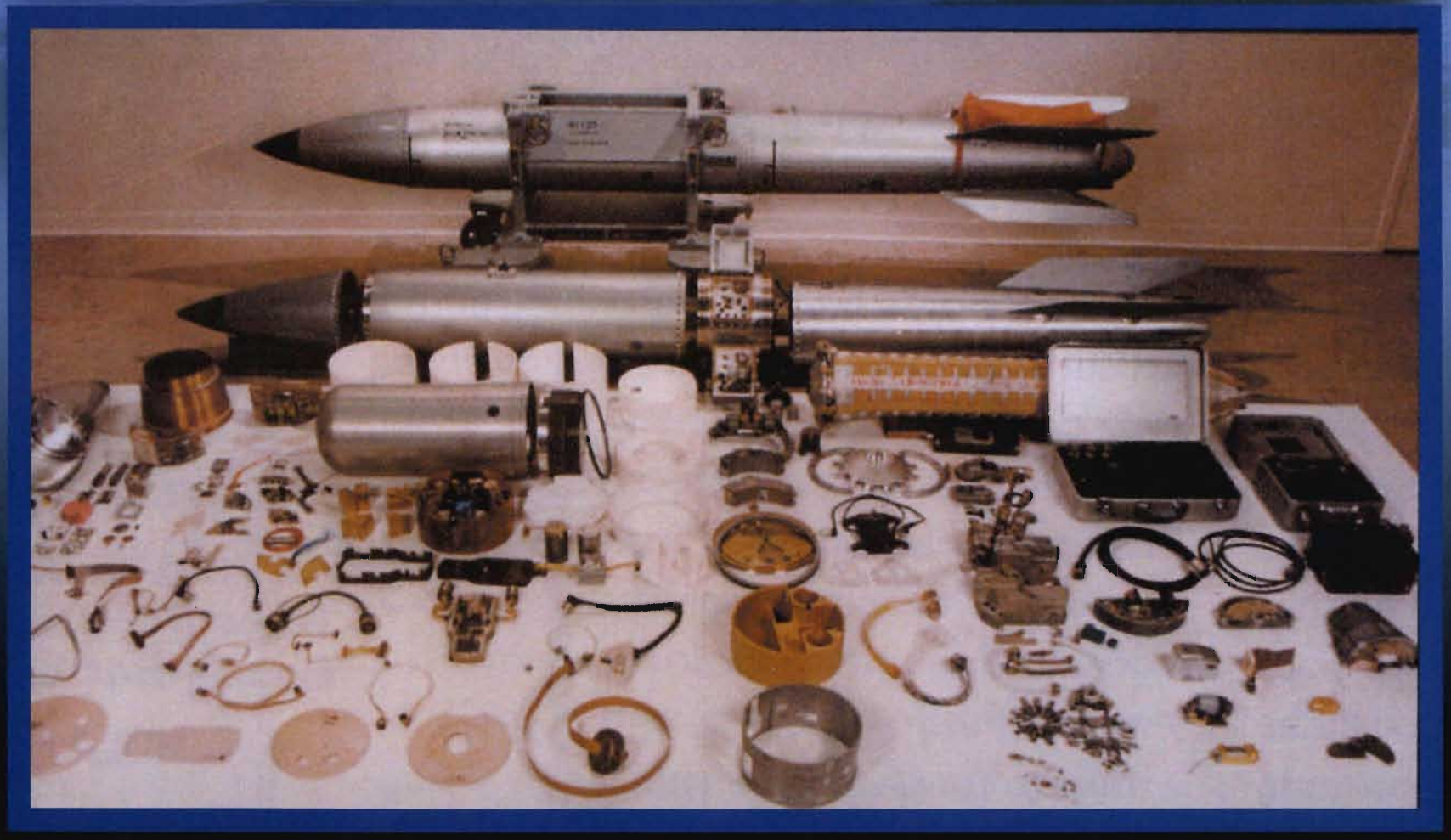
TA-55 Plutonium Complex at Los Alamos







B-61 Nuclear Bomb (>4000 parts)



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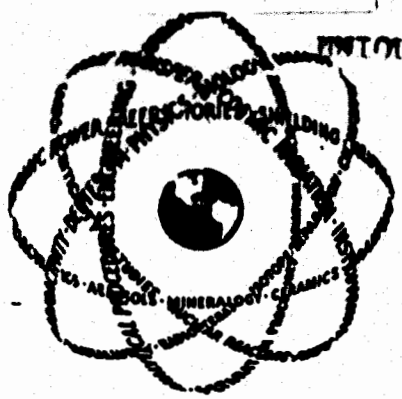
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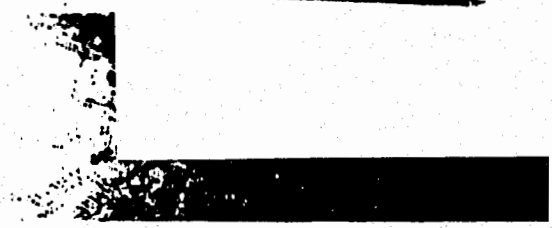
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AN INTRODUCTION TO NUCLEAR WEAPONS (U)

By
Samuel Glasstone

December 1962
[DTI Issuance Date]

University of California, Los Alamos Scientific Laboratory

and

University of California, Lawrence Radiation Laboratory, Livermore

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ABSTRACT

This document contains restricted data as defined in the Atomic Energy Act of 1954. Its transmittal or the disclosure of its contents in any manner to an unauthorized person is prohibited.

UNITED STATES ATOMIC ENERGY COMMISSION
Division of Technical Information

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FOREWORD

While this document has been published as a Headquarters, U. S. Atomic Energy Commission publication, it has as its genesis two 1954 Los Alamos Scientific Laboratory reports identified as LAMS-1632 and LAMS-1633, titled "Weapons Activities of LASL." These publications are well known and used extensively by those interested in nuclear weapons as basic handbooks on the principles of nuclear weapons development and technology. Dr. Samuel Glasstone has revised and consolidated the above reports incorporating information furnished by the Los Alamos Scientific Laboratory, Lawrence Radiation Laboratory–Livermore, The Sandia Corporation, and the Defense Atomic Support Agency.

This document has been prepared solely for reference purposes on the principles of atomic weapons development and should not be considered as a technical guide for designing nuclear weapons.

Since this issue contains highly sensitive atomic weapons information of significance to our national defense and security, all viewers are enjoined to insure its proper security protection at all times.

A. W. Betts
Major General, USA
Director of Military Application
U. S. Atomic Energy Commission

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In preparing this report, I have received invaluable assistance from members of the Lawrence Radiation Laboratory (Livermore), Los Alamos Scientific Laboratory, Defense Atomic Support Agency (Headquarters and Field Command), the Sandia Corporation, and the AEC Division of Military Application. Unfortunately, it is not possible to list the names of all those individuals who contributed either by providing information or by reviewing the draft manuscript or both. However, I wish to acknowledge my great indebtedness to them, for without their help this report could not have been produced. My special thanks are due to Lawrence S. Germain for his effective coordination of the contributions from LRL, Livermore.

S. G.

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rate.* Most of the neutrons produced in fission actually have higher energies, but they lose energy rapidly in (inelastic) collisions, so that they are brought below the threshold of about 1 Mev for significant fission of uranium-238. Consequently, the maintenance of a chain reaction in uranium-238 is impossible. Nevertheless, fission of this isotope by fast neutrons does take place and the energy released can make a significant contribution to the total energy produced in nuclear weapons.

1.9 Of the three fissile species, only uranium-235 is found in nature; the other two are produced by artificial nuclear reactions (§1.53). Furthermore, only two, namely, uranium-235 and plutonium-239, are being used in weapons. Although uranium-233 has fission characteristics which would appear to make it of interest for use in certain types of artillery shells of small caliber, the strong gamma-ray activity of associated products introduces serious fabrication and handling problems.

1.10 The fission process may be regarded as yielding three types of products: (a) lighter nuclei, called fission fragments, (b) neutrons, referred to as fission neutrons, and (c) energy. Thus, taking uranium-235 as typical, the fission act may be represented by

$$\text{Uranium-235} + n \rightarrow \text{Fission fragments} + 2 \text{ to } 3\ n + \text{energy}$$

where n indicates a neutron. These products will be considered in turn. It may be mentioned that the general discussion of the fission process given below is applicable to all three fissile substances. Such differences in behavior as do exist arise from differences in the average number of neutrons produced when fission occurs and in the relative probabilities (or cross sections) of fission and nonfission reactions for neutrons of a given energy.

Fission Products

1.11 Uranium-235 (and other) nuclei split up in about 40 different ways, although some of these modes of fission are more probable than others. This means that roughly 80 different nuclides (fission fragments) are formed in fission in various proportions. Nearly all, if not all, of the fission-fragment nuclei are radioactive, emitting beta particles and frequently also gamma rays. On the average, each fission fragment undergoes three stages of beta decay before attaining stability, so that there are ultimately formed over 200 different nuclear species, most of which are radioactive. The mixture of fission fragments and their decay products is referred to by the general name of fission products. As just indicated, it is a very complex system containing many radioisotopes, the half-lives ranging from a small fraction of a second to a million years. It is the fission product mixture which contributes nearly all of the radioactivity of the fallout produced by a nuclear explosion.

Fission Neutrons

1.12 The number of neutrons released when a nucleus undergoes fission varies somewhat with the particular mode of fission, but the average number of fission neutrons is well defined. The value depends on the energy of the neutrons which cause fission, and increases to some extent with increasing neutron energy. The results of estimates based on experimental measurements are given in Table 1.1 of the average number (ν) of neutrons produced per fission caused by (a) slow neutrons, i.e., neutrons of essentially zero energy, (b) neutrons of about 0.5 Mev energy, which is roughly the average energy of the neutrons which maintain the chain in a simple fission weapon, and (c) neutrons of 14-Mev energy which contribute greatly to the fission energy of boosted (§1.49) and many two-stage (§7.38) devices.

1.13 The neutrons emitted in fission fall into two categories, namely, prompt neutrons and delayed neutrons. The former are all released within something like 10^{-14} sec of the fis-

*A distinction is sometimes made between the "fissile" nuclei, such as uranium-235, etc., in which fission can be produced by a neutron regardless of its energy, and the "fissionable" nuclei, such as uranium-238 and thorium-232, which require neutrons of high energy to cause fission.

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sion process, but the latter continue to be emitted for a few minutes. For uranium-235 fission, the prompt neutrons constitute 99.35 percent of the total fission neutrons and for plutonium-239 they represent nearly 99.8 percent. Because the time scale in nuclear explosions is very short, delayed neutrons play essentially no part in the fission chain reaction. In reactors for the controlled release of nuclear energy, however, these neutrons are of great significance.

Table 1.1—Neutrons Released per Fission

Nuclide	Neutron Energy		
	~0 Mev	0.5 Mev	14 Mev
Uranium-235	2.43	2.49	4.1
Plutonium-239	2.80	2.85	4.9
Uranium-233	2.45	2.51	4.2

Fission Energy

1.14 The rough estimate made earlier indicated that about 200 Mev of energy are produced per nucleus undergoing fission. More precise calculations, based on nuclear masses, and experimental measurements have shown that this is a good approximation for both uranium-235 and plutonium-239. The atomic mass in grams, i.e., 235 grams of uranium-235, contains 6.02×10^{23} nuclei, and the complete fission of this amount of uranium-235 would yield $6.02 \times 10^{23} \times 200 = 1.20 \times 10^{25}$ Mev or 1.93×10^{19} erg, since 1 Mev is equal to 1.60×10^{-6} erg. Making use of the fact that 1 calorie is equivalent to 4.18×10^{7} ergs, it can be readily shown that complete fission of all the nuclei in 1 kilogram of fissile material would result in a total energy release of 2.0×10^{13} calories.

1.15 Only part of the energy of fission is immediately available in a nuclear explosion, since most of the radioactive decay energy of the fission products is released over a long period of time. It is usually accepted that about 90 percent of the fission energy contributes to the explosion, so that in a weapon the fission of 1 kilogram of material would produce explosive energy of about 1.8×10^{13} calories. The energy liberated in the explosion of 1 ton of TNT is taken to be 10^{9} calories, and so 1 kilogram of fissile (or fissionable) material is equivalent in explosive power to 18,000 tons, i.e., 18 kilotons (or 18 kt), of TNT.* From these results it is readily found that complete fission of 0.056 kg (or 56 grams) or of 1.45×10^{23} nuclei of fissile material produces the equivalent of 1 kt of TNT of explosive energy. In other words, the energy per fission is 7.03×10^{-24} kt TNT equivalent. In stating the energy yields (or, in brief, the yields) of nuclear weapons, the basic unit, for very low yields, is the ton, with the kiloton (or 1,000 tons), i.e., 1 kt, and the megaton (or 1,000,000 tons), i.e., 1 Mt, of TNT equivalent being used for higher yields.

THE FISSION CHAIN REACTION

Condition for Chain Reaction: Critical Size

1.16 The condition for a self-sustaining fission chain reaction is that, on the average, the neutrons released in one act of fission shall cause (at least) one subsequent fission. Since the average number of neutrons produced in an act of fission is greater than two (see Table 1.1), it would appear, at first sight, that a chain reaction in uranium-235 or plutonium-239 would be inevitable. However, this is not so, because an appreciable proportion of the neutrons pro-

*In some calculations, the equivalent of 1 kg of uranium-235 is assumed to be 17 kt whereas for plutonium-239 it is 19 kt. The value 18 kt per kg is a good average for most fission weapons.

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thus determined by the availability of the prompt neutrons, without regard to those which are delayed. This situation is often described as prompt critical. Since more than 99 percent of fission neutrons are prompt, the neglect of the delayed neutrons has little effect on the value of ν. In other words, the data in Table 1.1 may be taken as being approximately applicable to weapons. Critical masses determined by experiment (§1.29) include the contribution of delayed neutrons, so that the prompt critical mass is very slightly larger than the measured value. Again, the difference is not significant, although corrections can be applied if necessary.

Factors Affecting Critical Mass

1.22 The critical size (or mass) of a given fissile material depends on a number of factors, as mentioned earlier. For example, the shape (or geometry) of the system has an influence on criticality because of the variation in the volume-to-area ratio. As seen in §1.17, this ratio determines the fraction of neutrons lost by leakage from the system. The optimum condition of minimum critical mass is obtained for a sphere; this has the largest ratio of volume to area, so that the fraction of neutrons produced which escape from the system is less than for any other shape of the same mass. Thus, the critical mass of a sphere is less than for any other geometrical form of the given material.

DOE b(3)

1.23 As far as the composition of the material is concerned, it is evident that the presence of impurities will increase the critical mass of the fissile species. Apart from the fact that the impurity may cause a loss of neutrons by parasitic capture, it adds area to the system, which increases the probability of neutron escape, without the compensating production of neutrons by fission in the increased volume. Similar considerations apply to the situation in which a given fissile substance, e.g., plutonium-239, exists in two forms with different densities. The less dense form (delta-plutonium metal) has a higher critical mass than the more dense form (alpha-plutonium) because of the larger surface area for a given mass. The rate of neutron production by fission depends on the mass, i.e., the number of fissile nuclei, but the rate of loss by escape is greater for the delta-plutonium since the area is larger for the same mass.

1.24 The value of ν also affects the critical size. The larger the magnitude of ν, the smaller will be the critical size (or mass) under the same general conditions. If more neutrons are formed per fission, it will be possible to tolerate a somewhat larger loss and yet attain criticality. This is apparent from the fact that the critical condition is that $k = \nu - 1 = 1$, so that an increase in 1 can be compensated by an increase in ν. It is because its ν is appreciably larger, that the critical size of plutonium-239 is less than that of uranium-235, under equivalent conditions. Since the densities of plutonium and uranium are not greatly different, the same relationship applies to the respective critical masses (see Table 1.2).

Table 1.2—Critical Masses of Spheres

Fissile Material	Density (g/cm^3)	Critical mass (kg)	
		Bare	Reflected
Uranium-235 (93.2 wt.%)	18.8	52.2	
Plutonium-239 (α)*	19.6	10.4	
Plutonium-239 (δ)†	15.8	16.5	

DOE b(3)

*Contains 4.5 wt.% plutonium-240.

†Contains 4.5 wt.% plutonium-240 and 1.0 wt.% gallium δ-phase stabilizer.

1.25 For a specified shape and composition, the size of a critical system can be decreased by surrounding it with a material which scatters some of the escaping neutrons back

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into the fissile core. By reducing the fraction of neutrons which escape completely, a smaller size (or mass) can become critical. Such a scattering material, on account of its function, is sometimes referred to as a neutron reflector.

1.26 In nuclear weapons, the fissile material is surrounded by a tamper or, more specifically, an inertial tamper, the mass of which delays expansion of the exploding material and permits a higher energy yield to be obtained from the system undergoing fission, as will be seen later. This inertial tamper also serves as a neutron reflector or neutronic tamper. In some cases, however, the neutronic aspect is more important than the inertial character of the tamper.

1.27 As is to be expected, increasing the thickness of the tamper decreases the escape of neutrons and thus makes possible a smaller critical mass of the core of fissile material. However, it has been shown by calculations and verified experimentally that when the neutronic tamper thickness reaches a certain value, there is little more to be gained by a further increase of thickness (Fig. 1.2). Thus, when the thickness is about two neutron scattering mean

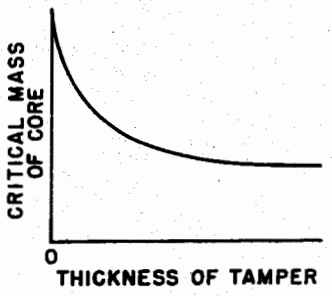


Figure 1.2

free paths, the effectiveness in decreasing the critical mass is within a few percent of that for an infinitely thick tamper.* In natural uranium, which is sometimes used as a tamper, the scattering mean free path of fast (1 Mev) neutrons is about 4 cm, i.e., 1.6 in., in metal of normal density. The value is proportionately less in compressed uranium of higher density. In weapons of low mass, beryllium is a common tamper material; the scattering mean free path is somewhat longer than in uranium because of the lower density.

1.28 Another important factor which affects the critical size is the energy (or speed) of the neutrons causing fission. For several reasons, some of which will be explained later, nuclear weapons are designed so that the fission chain is maintained by fast neutrons, with energies in the range of approximately 0.1 to 2 Mev. In the subsequent treatment it will be assumed, therefore, that fast-neutron fission makes the main contribution to the chain reaction.

Determination of Critical Mass

1.29 Critical masses can now be calculated with a fair degree of accuracy, provided all the conditions are known exactly. It is desirable, however, to check these values by experimental measurements. Because of the danger involved in handling critical assemblies, the general procedure is to extrapolate from observations made on a number of subcritical systems of increasing mass.

1.30 It was seen in §1.20 that the introduction of S neutrons into a fissile material results in the presence of kS neutrons in the first generation, k^2S in the second, and so on. If a

*The scattering mean free path is the average crow-flight distance a neutron travels before undergoing a scattering collision with a nucleus in the given tamper material.

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neutrons for initiating fission chains. In addition, the high-energy (14 Mev) neutrons liberated in the D-T reaction are used in many fission weapons to achieve what is known as "boosting." Neutrons from the D-T reaction are introduced at a later stage of the fission chain in order to maintain and enhance the progress of the fission reactions. There is a considerable increase in the energy released because of the greatly improved efficiency in utilization of the fissile material. The energy contributed by the D-T fusion reaction is quite small in comparison with that from fission.

PRODUCTION OF WEAPONS MATERIALS

Uranium-235

1.50 The two important fissile materials, namely, uranium-235 and plutonium-239, are both produced from natural uranium but by entirely different procedures. Ordinary uranium contains about 0.7 percent of uranium-235, together with about 99.3 percent of uranium-238 and a trace (0.006 percent) of uranium-234. The proportion of uranium-235 is increased by a process involving diffusion or, more correctly, effusion through porous barriers of the vapor of uranium hexafluoride (UF_6) made from natural uranium. The hexafluoride of the lighter isotope diffuses more rapidly than does that of the heavier species, and by the use of several thousand diffusion stages enrichments of over 90 percent are obtained, i.e., the material produced contains over 90 percent of uranium-235. The most common product for weapons use consists of about 93.5 weight percent uranium-235, the remainder being mainly uranium-238 and a small proportion of uranium-234. This product is commonly known as "oralloy,"* the two initial letters standing for Oak Ridge, where the material was first made in quantity.

[redacted] DOE 6(3)

1.51 The highly enriched uranium hexafluoride obtained from the gaseous diffusion plant is converted into the tetrafluoride (UF_4) by reduction with hydrogen (mixed with some fluorine). The tetrafluoride, which is a solid with a high melting point (close to 1000°C), is mixed with calcium and heated in a closed steel vessel lined internally with a refractory material. The calcium reduces the uranium tetrafluoride to uranium metal which is separated from the slag of calcium fluoride. Volatile impurities are removed by heating the liquid metal in a vacuum and the resulting product is of a high degree of purity.

1.52 The residual material from the isotope separation (gaseous diffusion) plant consists of uranium hexafluoride which has been depleted in uranium-235. In other words, it contains more than the normal 99.3 percent of uranium-238. This is converted into uranium metal by a procedure similar to that described above. It is referred to as depleted uranium or, in the weapons program, as D-38. At one time it was called Q-metal, but this name is not now in common use.

Plutonium-239

1.53 The element plutonium does not occur in nature, except in insignificant traces. Consequently, the plutonium-239 used in weapons is obtained artificially by a series of nuclear reactions resulting from exposure of uranium-238 to slow neutrons in a nuclear reactor. A nuclear reactor is a device in which a fission chain reaction is taking place in a controlled manner, as against the deliberately uncontrolled chain reaction in a weapon. If a material of low mass number, called a moderator, is present, in addition to fissile material, the fission neutrons are slowed down. Such a nuclear reactor is thus a good source of slow neutrons.

---

*The "alloy" part of the name originated from the designation Tube Alloys Limited applied to the British wartime atomic energy project. Natural uranium metal was thus called "tuballoy," a term still in common use, and then oralloy was adopted for the uranium-235 enriched material.

[redacted]

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1.54 Uranium-238 nuclei capture slow neutrons quite readily to form a higher isotope, uranium-239, with the emission of gamma radiation; thus, the (n,γ) reaction

$$_{92}U^{238} + {}_0n^1 \rightarrow {}_{92}U^{239} + \gamma$$

occurs, where the subscripts give the atomic numbers and the superscripts the mass numbers in each case; the neutron ($_0n^1$) has a charge (atomic number) of zero and a mass of unity. The uranium-239 produced by neutron capture is radioactive, with a half-life of 23 min, emitting a beta particle. Representing the latter by $_{-1}\beta^0$, since it carries a unit negative charge and has essentially no mass, the radioactive decay process may be written as

$$_{92}U^{239} \rightarrow {}_{-1}\beta^0 + {}_{93}Np^{239}$$

the product being an isotope of mass number 239 of an element of atomic number 93. This element, called neptunium (Np), is virtually nonexistent in nature.

DOE 6(3)

[redacted]

1.55 Neptunium-239 is also radioactive with a half-life of 2.3 days; it emits a beta particle according to the reaction

$$_{93}Np^{239} \rightarrow {}_{-1}\beta^0 + {}_{94}Pu^{239}$$

so that the product has a mass number of 239 and an atomic number of 94. The name plutonium, symbol Pu, has been given to the element with this atomic number. The isotope plutonium-239 is an alpha-particle emitter with a fairly long half life—about 24,000 years—so that it is relatively stable. It may be mentioned that the decay product of plutonium-239 is the fissile uranium-235, which has a half-life of about 9×10^8 years. Hence, as far as fission is concerned, plutonium-239 could be stored for thousands of years with only minor deterioration. The little deterioration which does occur arises mainly from the fact that the average number of neutrons, ν, produced by fission of uranium-235 is somewhat less than that from plutonium-239 (§1.12).

1.56 For the production of plutonium-239, natural uranium metal is used as the fuel material in a nuclear reactor with graphite (Hanford) or heavy water (Savannah River) as the moderator. The uranium-235 in the fuel sustains the fission chain reaction and produces neutrons, some of which are captured by the uranium-238 with the consequent formation of plutonium-239, as described above. After being in the reactor for an appropriate time, the "spent" fuel is removed, dissolved in nitric acid, and the plutonium is extracted from the solution by the use of certain organic solvents. It is then re-extracted into a water medium to give an aqueous solution of the nitrate, from which the plutonium is precipitated either as the peroxide or the oxalate. The solid compound is separated and heated with a mixture of hydrogen fluoride gas and oxygen to obtain plutonium tetrafluoride (PuF_4). The latter is finally reduced to plutonium metal with calcium (plus iodine).

1.57 Metallic plutonium exists in six different allotropic forms between room temperature and the melting point (640°C). The temperature ranges over which the various forms (or phases) are stable are shown in Table 1.3. It is seen that alpha-plutonium, referred to in §§1.23 and 1.34, which has a density of 19.6 g/cm^3, is stable at ordinary temperatures. The high density is advantageous from certain weapon standpoints, since it permits attainment of criticality in a smaller mass than is possible with other forms of plutonium (cf. Table 1.2). On the other hand, alpha-plutonium is brittle and difficult to fabricate. Furthermore, the presence of certain impurities retards the attainment of the alpha-phase equilibrium, so that fabricated parts exhibit dimensional instability. However, if these impurities are avoided, the dimensional instability problem does not arise.

1.58 Although delta-plutonium is normally stable in the temperature range of 319 to 451°C, the addition of 1 weight percent of gallium to plutonium stabilizes the delta phase at or-

[redacted]

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dinary temperatures. The plutonium used in most stockpile weapons is in the stabilized delta form. The material is much less brittle and easier to fabricate than alpha-plutonium: in fact delta-plutonium is said to resemble aluminum in this respect whereas the alpha-phase is more like cast iron. Delta-plutonium was used in the earliest implosion weapons because its low density permitted the use of a larger mass of subcritical fissile material (Table 1.2), thereby making possible an increase in the total energy yield. This aspect of weapons design is, however, no longer significant.

Table 1.3 — Properties of Solid Phases of Plutonium

Phase	Stability range	Density (g/cm^3)
Alpha (α)	Up to 120°C	19.6 (25°C)
Beta (β)	120 to 206°C	17.8 (150°C)
Gamma (γ)	206 to 319°C	17.2 (210°C)
Delta (δ)	319 to 451°C	15.9 (320°C)
Delta prime (δ')	451 to 476°C	16.0 (465°C)
Epsilon (ϵ)	476 to 640°C (m.p.)	16.5 (510°C)

Plutonium-240

1.59 As the plutonium-239 accumulates in the reactor in which it is produced, it also captures neutrons, the rate of capture being proportional to the neutron density (or flux) in the reactor and to the concentration of plutonium-239 nuclei. The reaction which takes place is

$$_{94}Pu^{239} + {}_0n^1 \rightarrow {}_{94}Pu^{240} + \gamma$$

the product being plutonium-240, an alpha emitter of about 6600 years half-life. The two isotopes of plutonium are not separated from one another in the chemical process used for the extraction of this element from the reactor fuel. Hence, plutonium-239 is always associated with a certain proportion of plutonium-240, the amount of the latter increasing, with both the exposure time and neutron density in the reactor, up to a limiting value of about 35 percent.

1.60 In a simple (unboosted) implosion type weapon, it is desirable that the plutonium-240 content be as small as possible for two reasons: (a) the high spontaneous fission rate of plutonium-240 causes a large neutron background (§1.37) which can result in the initiation of a fission chain before the optimum time, and (b) the fission of plutonium-240 requires mostly neutrons of high energy and, in addition, the ν value is smaller than for plutonium-239 so that it acts, to some extent, as an inert diluent.* Consequently, if plutonium-240 is present, the mass of plutonium-239 required for criticality is larger than would be the case for pure material (§1.23). [redacted] DOE b(3) It should be noted that to obtain a product with a small proportion of plutonium-240, the uranium fuel elements can be permitted to remain in the reactor for only a short time before they are removed and processed for the extraction of plutonium. As a result, the smaller the plutonium-240 content, the higher the cost of the material produced.

1.61 In evaluating the cost of the plutonium in a weapon, it must be recognized that the higher the plutonium-240 content the smaller the cost per unit mass of plutonium-239, but the larger the mass required for criticality. The actual cost per crit, which is the important cri-

*Fission of plutonium-240 exhibits an appreciable resonance for neutrons of about 1-ev energy. Otherwise, the cross sections are low except at high neutron energies.

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terion, is thus determined by two opposing factors. The weapon cost first decreases and then increases as the proportion of plutonium-240 is increased. However, cost is not the only factor to be taken into account in the choice of weapon material. An important consideration, known as "one-point safety" (§5.13), is favored in some (but not all) circumstances by the use of material containing higher proportions of plutonium-240. [redacted] DOE b(3) This is regarded as the best compromise at the present time, although it may be subject to change with circumstances.

1.62 For a production reactor of a given type, the plutonium-240 content of the material produced depends on the neutron density (or reactor power) and the exposure time. Consequently, the quality of plutonium was at one time described in terms of megawatt-days of exposure in the reactor per ton of uranium fuel, i.e., in MWD/T units. This unit is not very precise because the reactor power is not uniform throughout its volume, so that the plutonium-240 content corresponding to a given MWD/T value will vary with the location of the fuel in the reactor. It also depends upon the characteristics of the production reactor, so that it is different for the Hanford (graphite moderated) and Savannah River (heavy-water moderated) reactor products. An alternative method for expressing quality is the number of grams of plutonium per ton of fuel removed for processing, generally indicated by g/T; the higher the g/T value the greater the plutonium-240 content. Because 1 MWD of reactor energy produces roughly 1 gram of plutonium, the values are approximately equal numerically in g/T and MWD/T units.

1.63 The two foregoing methods of indicating the quality of plutonium have now been replaced by the actual statement of the weight percent of plutonium-240. Some of the older fission weapons required plutonium of low plutonium-240 content ("clean" plutonium); the purest material generally used contained about 1.5 percent of plutonium-240 (about 220 MWD/T). [redacted] DOE b(3)

1.64 Another way of expressing the amount of plutonium-240 is based on direct measurement of the rate of neutron emission from the material. These neutrons arise mainly from the spontaneous fission of plutonium-240. The result is expressed as the number of neutrons emitted per gram per second, abbreviated to ngs. A rough "rule of thumb" is that the ngs value is 10.5 times the percentage of plutonium-240. The characteristics of three Hanford production materials with different plutonium-240 contents are given in Table 1.4.

Table 1.4—Characteristics of Hanford Plutonium

Plutonium-240 (percent)	MWD/T	Neutrons/gram-sec (ngs)
7.1	800	75
5.6	600	58
3.85	400	40

*Continued exposure in a reactor results in the conversion of some plutonium-240 into fissile plutonium-241 as a result of neutron capture. Thus, beyond a certain point the usefulness of dirty plutonium as a weapons material may increase.

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Production of Neutrons

1.65 In a fission weapon, the chain reaction is initiated by the introduction of neutrons into a critical or supercritical system. Consequently, the general methods for producing neutrons in weapons will be reviewed here. One of the simplest procedures for obtaining neutrons is by the action of alpha particles on certain light elements, notably beryllium; processes of this kind are referred to as (α,n) reactions. Recalling that the alpha particle is actually a helium nucleus, the reaction is represented by

$$_2He^4 + _4Be^9 \rightarrow _6C^{12} + _0n^1$$

1.66 A convenient source of alpha particles, which was used extensively at one time in fission weapons, is the radioelement polonium-210. This isotope has certain advantages, associated with corresponding drawbacks. It does not emit gamma rays, so that there is no neutron production by the (γ,n) reaction which might otherwise occur even when the polonium-210 and beryllium are separated in such a manner as to prevent access of alpha particles to the latter. Moreover, the polonium-210 is easy to produce by exposure of ordinary bismuth to neutrons in a nuclear reactor, when the (n,γ) reaction

$$_{83}Bi^{209} + _0n^1 \rightarrow _{83}Bi^{210} + \gamma$$

takes place. The bismuth-210 is a beta emitter with a half-life of 5 days, so that it soon decays to form polonium-210; thus,

$$_{83}Bi^{210} \rightarrow _{-1}\beta^0 + _{84}Po^{210}$$

However, the production of polonium-210 in this manner means that fewer neutrons are available for the conversion of uranium-238 into plutonium-239.

1.67 The moderately short half-life of polonium-210—138.4 days—means that it emits alpha particles rapidly and a small quantity can thus provide a strong neutron source in conjunction with beryllium. But the short half-life is also a serious disadvantage, because the activity falls off relatively rapidly. In one year, the alpha activity, and hence the rate of neutron production, will have decreased to 10 percent and in two years to 1 percent of its initial value.

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CHAPTER 2

THE FISSION PROCESS IN WEAPONS

INCREASE OF NEUTRON POPULATION

The Multiplication Rate: Alpha

2.1 No matter how it originates, an explosion is associated with the very rapid liberation of a large amount of energy within a restricted space. If the energy is to be produced by fission, then an essential condition for explosion is a very high neutron density, since the rate of fission, and hence the rate of energy release, is proportional to the number of neutrons per unit volume. It is of interest, therefore, to examine the factors which lead to a high neutron density, since these will form a basis for fission weapon design.

2.2 In accordance with the definition of the effective multiplication factor, k, given in §1.19, it follows that for every n neutrons present at the beginning of a generation there will be nk neutrons at the beginning of the next generation, so that the gain of neutrons is $n(k-1)$ per generation. The rate of gain, dn/dt, may then be obtained upon dividing the actual gain by the average time, τ, between successive fission generations; hence,

$$\frac{dn}{dt} = \frac{n(k-1)}{\tau} \tag{2.1}$$

Equation (2.1) will be strictly correct only if delayed neutrons play no part in maintaining the fission chain. As already stated (§1.13), this condition is applicable, to a good approximation, to nuclear fission weapons.

2.3 The quantity $k-1$, which is the excess number of available neutrons per fission, may be represented by x, i.e.,

$$x \equiv k-1 \tag{2.2}$$

and then equation (2.1) becomes

$$\frac{dn}{dt} = \frac{x}{\tau} n \tag{2.3}$$

The time rate of increase (or decrease) in neutron population can be expressed in the general form

$$\frac{dn}{dt} = \alpha n \tag{2.4}$$

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where α is the specific rate constant for the process which is responsible for the change in the number of neutrons. In nuclear weapons work this constant is called the multiplication rate or merely "alpha." Comparison of equations (2.3) and (2.4) shows that for a fission chain reaction

$$\alpha = \frac{x}{\tau} \tag{2.5}$$

2.4 The foregoing results are applicable regardless of whether x, and hence α, is positive, zero, or negative. For a subcritical system, $k < 1$ (§1.20), i.e., $k - 1$ is negative; in these circumstances x is negative and so also is α. It follows from equation (2.4) that dn/dt is then negative and the number of neutrons in the system will decrease with time. Consequently, in agreement with previous conclusions, the fission chain in a subcritical system will eventually die out because of the steady decrease in the neutron population. When the system is just critical, $k = 1$, and x and α are both zero; the number of neutrons will thus remain constant. Finally, for a supercritical system, $k > 1$, and x and α are positive; there will then be a steady increase in the neutron population. Since dn/dt is proportional to n, by equation (2.4), it is evident that in a supercritical system, the number of neutrons will grow at increasingly faster rates as n increases.

2.5 Another aspect of the significance of α becomes apparent when equation (2.4) is written in the form

$$\frac{dn}{n} = \alpha \, dt$$

If α is assumed to remain constant, this expression can be readily integrated between the time limits of zero, when the number of neutrons present is n_0, and t, when the number is n. The result is

$$n = n_0 e^{\alpha t} \tag{2.6}$$

where, as usual, e is the base of natural logarithms. This expression, like those given above, is applicable regardless of whether α is positive, zero, or negative. If α is known, equation (2.6) can be used to calculate the neutron population at any time t relative to the value at any arbitrary zero time. It can also be seen from equation (2.6) that $1/\alpha$ is the time period during which the number of neutrons changes by a factor e; consequently, $1/\alpha$ is often referred to as the e-folding time, i.e., the time in which there is an e-fold change in the neutron population.

Determination of Alpha

2.6 The value of α is a highly important quantity in weapons design, as will shortly be apparent. Attempts are made to estimate it theoretically from the neutronic and hydrodynamic characteristics of the system, but there are many uncertainties involved and experimental measurements are desirable. In weapons tests, the determination of alpha is one of the most important diagnostic requirements. The methods used under these circumstances are described in Chapter 8. The present treatment will be restricted to procedures which can be used in the design phase without an actual test of the weapon.

2.7 Since a supercritical (or even a critical) mass cannot be handled safely under ordinary conditions, experimental measurements of α are made with a mass that is slightly subcritical. Into this assembly is injected a burst of neutrons and these neutrons initiate a large number of chains. However, since the system is subcritical, α will be negative and so the number of neutrons will decrease after the initial increase. By determining a quantity proportional to the neutron population as a function of time, with neutron counters located outside the assembly, it is possible to determine α by means of equation (2.6). The α obtained from the decrease in neutron population in the early stages is the so-called prompt value, required for weapons studies in which the delayed neutrons play no part.

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2.8 Another method is to introduce a single neutron at intervals into a slightly subcritical system. One (effective) neutron starts a fission chain which soon dies out; then another neutron starts a second chain which dies out, and so on for the duration of the experiment. Thus, instead of being subjected to the neutrons from a large number of chains almost simultaneously, the counters are exposed over an appreciable period to neutrons from a large number of chains one at a time. The method is thus statistical in character. The neutron counting is carried out by means of a multichannel time-delay circuit. The first channel is activated by entry of a neutron; then, after a pre-determined interval, a second channel is activated for a short time; after a further interval, a third channel is activated, and so on for intervals ranging from 0.25 μsec to a total of a few milliseconds. From the accumulated counts for the various channels, the time rate of decay of the prompt neutrons after fission can be determined and α calculated.

2.9 The values of α obtained as described above apply to the particular subcritical system used. In order to estimate what α would be in a supercritical (weapon) assembly of the same materials, an extrapolation procedure can be employed. By means of a number of measurements with different assemblies, α can be determined as a function of the number of (prompt) crits present. The values could then be extrapolated to give α for the number of crits expected at the time of initiation of the weapon. Such a procedure is highly uncertain since it involves extrapolation from a series of assemblies which are slightly subcritical to one which is highly supercritical.

Conditions for Nuclear Explosion

2.10 It was pointed out in §2.1 that the essential condition for a nuclear fission explosion is a very high neutron density. Equation (2.6) shows that if a large density n is to be attained within a short time, α must be large. In general, the magnitude of α determines the efficiency of a nuclear explosion, and it is of interest to consider how α may be made as large as possible.

2.11 According to equation (1.4), k is equal to $\nu - l$, where ν is the average number of neutrons produced in each act of fission and l is the number lost by escape and in other ways upon utilizing this result, together with equations (2.2) and (2.5) it follows that

$$\alpha = \frac{x}{\tau} = \frac{\nu - l - 1}{\tau} \tag{2.7}$$

so that to increase α it is necessary that $\nu - l - 1$ be large and τ be small. The value of ν is a specific property of the fissile material for fission by neutrons of a given energy. Since ν increases with neutron energy, it would appear to be advantageous from this standpoint if most of the fissions in a weapon were caused by fast neutrons. The relative neutron loss, l, can be decreased by making the system highly supercritical, e.g., by assembly or compression. If the volume increases, the loss of neutrons per fission increases and α will decrease accordingly. The importance of this effect of volume change will be seen later (§2.23).

2.12 A highly significant contribution to the magnitude of α is made by the fission generation time, τ. This is approximately equal to λ, the fission mean free path of the neutrons in the core material, divided by the (average) speed, v, of the neutrons causing fission, i.e.,

$$\tau \approx \frac{\lambda}{v} \tag{2.8}$$

so that in a fission weapon it is desirable that the ratio λ/v be as small as possible. It should be noted that the fission mean free path in equation (2.8) is not the same as the mean free path for all interactions used in §1.43. The λ employed here is the average (crow-flight) distance a neutron travels before it is captured in a fission reaction.

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2.13 The fission mean free path is equal to $1/N\sigma_f$, where N is the number of fissile nuclei per cm^3 and σ_f is the fission cross section.* Hence, from equation (2.8),

$$\tau \approx \frac{1}{N\sigma_f v} \tag{2.9}$$

so that the generation time is inversely proportional to the produce $\sigma_f v$. The value of σ_f decreases as v increases but the product is 2×10^9 (in 10^{-24} cm^3/sec units) for fast neutrons of 1-Mev energy compared with 10^8 for slow neutrons. Hence, the fission generation time is appreciably shorter for fast than for slow neutrons. Actually, the situation is worse for slow neutrons than would appear from a comparison of the values of $\sigma_f v$ because the effective generation time for these neutrons includes the slowing-down time and this is considerably longer than $\sigma_f v$ alone would indicate.

2.14 From the information already given, it is possible to make a rough, order-of-magnitude estimate of α. As seen from Table 1.1, ν is about 2.5 to 3; the loss, l, of neutrons per fission may be taken as 0.5 to 1, and so, by equation (2.2), x is close to unity for a highly supercritical system. For uncompressed uranium-235 or plutonium-239, the number, N, of nuclei per cm^3 is roughly 0.5×10^{23} and, as seen above, $\sigma_f v$ for fast-neutron fission is $2 \times 10^9 \times 10^{-24}$ cm^3/sec. It follows, therefore, from equation (2.7) and (2.9) that

$$\alpha \approx (0.5 \times 10^{23})(2 \times 10^{-15}) \approx 10^8 \text{ sec}^{-1}$$

Thus, for fast-neutron fission, α is about 10^8 sec^{-1} in a supercritical system and τ, the generation time, is roughly 10^{-8} sec (or 1 shake). It is the common practice to express values of α in reciprocal shakes, i.e., 10^8 sec^{-1} units, so that in the rough calculation made above α is approximately 1 $shake^{-1}$. Experimental measurements, both in the laboratory and at weapons tests, show that α is indeed of this order of magnitude.†

2.15 It is evident that in order to achieve an efficient nuclear explosion, fission should be brought about by fast neutrons, as far as possible. For such neutrons, the factors ν and τ, and to some extent l, favor a high value of α and, hence, a rapid increase in the neutron population. Except in certain special cases, appreciable amounts of elements of low mass number, which slow down neutrons, are consequently kept out of the core of a fission weapon.

2.16 According to equation (2.9), the fission generation time for neutrons of a given energy (or velocity) is inversely proportional to the number, N, of fissile nuclei per cm^3. It follows, therefore, that τ is inversely proportional to η, the core compression ratio; thus

$$\tau \propto \frac{1}{\eta} \tag{2.10}$$

Consequently, the generation time can be decreased, and the value of α increased, by compression of the core material.

2.17 In addition to the effect on τ, compression also causes a marked decrease in l, for the reason given in §1.40. This also contributes to an increase in α, as follows from equation (2.7). It is seen, therefore, that compression of the core will cause an increase in α because of the decrease in both τ and l.

Explosion Time

2.18 According to the arguments in §2.14, x is approximately equal to unity and so, by equation (2.5), $1/\alpha$ is roughly equal to τ, the generation time. It is thus possible to write equation (2.6) in the approximate form

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*For the present purpose it is sufficient to regard the cross section as the effective area in sq cm of a nucleus for a particular reaction (or reactions). Cross sections vary with the neutron energy and the fission cross sections for uranium-235 and plutonium-239 have been measured over a large energy range.

†Some workers prefer to express α in reciprocal microseconds.

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material, expansion of the core should be delayed. This important function is fulfilled by the inertial tamper. In boosted weapons, the introduction of neutrons from an extraneous (D-T) source results in a considerable increase in the fission rate before the system expands appreciably. The inertial tamper is then less important than in an unboosted device.

2.24 [redacted] DOE 6(3)

In some weapons, however, there will be many neutrons present at the time of initiation. If, for example, there are 100 neutrons, i.e., 10^2 or $e^{4.6}$, there will be the equivalent of nearly 5 "generations" of neutrons at the start of the chain. [redacted] DOE 6(3)

EFFICIENCY OF FISSION WEAPONS

Definition of Efficiency

2.25 The efficiency, ϕ, of any weapon may be defined as the ratio of the energy actually developed when it explodes, i.e., the energy yield, to the total energy available; thus,

$$\phi = \frac{\text{Energy yield}}{\text{Energy available}} \tag{2.13}$$

In other words, the efficiency is the fraction of the total energy available which is actually released in the explosion. In the case of a fission weapon, this is equal to the ratio of the quantity of fissile material which actually suffers fission to the total amount present in the weapon. The efficiency of a weapon is generally expressed as a percentage, and so it is equal to ϕ, as defined by equation (2.13), multiplied by 100. There are several factors which determine the efficiency and some of these will be discussed below.

2.26 It is of interest to mention, in passing, that the efficiency of the earliest implosion weapons wa[redacted] DOE 6(3) (§1.36). This accounts for the fact that devices of the latter type have occupied a secondary place in the development of fission weapons, except for special purposes.

Calculation of Efficiency: Machine Methods

2.27 At the present time, the efficiency or, more correctly, the energy yield of a weapon is determined by machine calculations based on "codes" which have been developed to represent the behavior of the fission chain system. [redacted] DOE 6(3) from initiation up to this time, the material is essentially stationary or is still being compressed and only a small proportion of the total energy has been liberated. The treatment takes into account the neutronic behavior, the hydrodynamics, and heat flow; the motion of a series of concentric shells (or "mass points") is followed until the rate of energy release by fission has fallen almost to zero. The total yield includes the energy released after the system has expanded and become subcritical. Although self-sustaining chain propagation is no longer possible, convergent-chain interaction of the many neutrons and fissile nuclei still present will result in considerable energy production. This may amount to some 30 percent or more of the total yield.

The Bethe-Feynman Formula

2.28 Prior to the development of computing machine procedures, and before data were available from test explosions for comparison and normalization purposes, fission weapon

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efficiencies were estimated by the method of Bethe and Feynman. The basic formula is admittedly approximate, since it involves several simplifying assumptions. However, its derivation is useful in the respect that it provides a model of the explosion of a fission weapon and indicates, qualitatively at least, some of the factors which affect the efficiency of the explosion. The treatment given below is applicable to pure fission systems and not after boosting occurs.

2.29 As a result of the energy liberated in fission, very large pressures ($\sim 10^9$ atm) are developed in the core, and the core-tamper interface consequently receives a large outward acceleration. This causes highly compressed tamper material to pile up just ahead of the expanding interface, in an effect referred to as the "snowplow" phenomenon, because of the similarity to the piling up of snow in front of a snowplow. The inertia of the compressed tamper delays expansion of the core, so that a considerable pressure gradient builds up from the center of the core to its outer surface.

2.30 Furthermore, because of the delayed expansion, it may be supposed that the volume of the compressed (supercritical) core remains essentially constant during the first [redacted] so generations following initiation of the fission chain, i.e., up to explosion time. After this interval, almost the whole of the energy is released within an extremely short period, during which time the supercritical core expands rapidly until it becomes subcritical. Although there is an appreciable release of energy even while the system is subcritical, as mentioned in §2.27, it will be postulated that energy production ceases when the dimensions are just critical. It will be assumed, further, that no energy escapes during the short period of expansion from maximum supercriticality to the point where the system becomes subcritical.

2.31 Let R be the radius of a spherical core at the point of maximum supercriticality; then, in accordance with the postulate made above, this will remain unchanged until explosion time. Subsequently, the energy density of the system becomes so large that mechanical effects begin and the core starts to expand. Suppose that when the core has expanded by a fraction δ, so that the radius is $R(1 + \delta)$, the system is just critical (Fig. 2.1); beyond this point it will be subcritical. The self-sustaining fission chain will then end and, in accordance with the approximation postulated above, there will be no further release of energy.

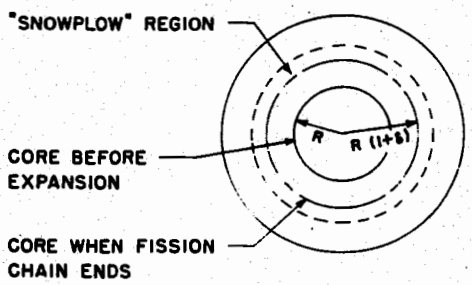


Figure 2.1

2.32 Consider a thin shell of material in the core, of volume dV and thickness dR; the cross sectional area of the shell is then dV/dR. If dP is the pressure difference on the two sides of this shell, caused by the liberated fission energy, the net outward force, dF, to which the shell is subjected, i.e., pressure × area, is then

$$dF = dP \frac{dV}{dR} = \frac{dP}{dR} dV \tag{2.14}$$

where dP/dR is the pressure gradient in the given shell. As a reasonable approximation, it may be supposed that the pressure gradient is essentially constant across the core radius, so that

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$$\frac{dP}{dR} \approx \frac{P}{R} \tag{2.15}$$

where P is the total difference in pressure from the center of the core to the outer surface before expansion occurs. Hence, from equations (2.14) and (2.15),

$$dF \approx \frac{P}{R} dV \tag{2.16}$$

2.33 The time required for the core to expand from radius R to $R(1 + \delta)$, i.e., a distance of $R\delta$, is about 7 generations, as seen in §2.21. However, as a rough approximation, this may be taken as $1/\alpha$, where α is the multiplication rate just prior to explosion time. The mean outward acceleration of the core material, and of the shell dV, may consequently be expressed as $R\delta\alpha^2$. The mass of the shell is ρdV, where ρ is the core density; hence, by Newton's second law of motion, i.e., force = mass × acceleration, the force dF acting on the shell is given by

$$dF \approx \rho dV \times R\delta\alpha^2$$

Upon comparing this result with equation (2.16), it is seen that

$$P \approx \rho R^2\alpha^2\delta \tag{2.17}$$

2.34 At the existing temperature the core will be gaseous and if, as postulated, the loss of energy from the system during the initial expansion is negligible, it may be considered as a gas undergoing an adiabatic process. The total energy of such a gas, which may be taken to be equal to the energy of the core, is then

$$E = \frac{PV}{\gamma - 1} \tag{2.18}$$

where γ is the ratio of the specific heats of the gas. Using equation (2.17) for P and writing M/ρ for the volume of the core, M being the mass, equation (2.18) becomes

$$E \approx \frac{MR^2\alpha^2\delta}{\gamma - 1} \tag{2.19}$$

2.35 If ϵ is the energy released in the complete fission of unit mass of core material, then the total energy available in the core is $M\epsilon$, and the efficiency, according to equation (2.13), is $E/M\epsilon$, where E is given by equation (2.19); consequently,

$$\phi = \frac{E}{M\epsilon} \approx \frac{R^2\alpha^2\delta}{(\gamma - 1)\epsilon} \tag{2.20}$$

It should be pointed out that in the foregoing derivation no allowance has been made for depletion of the core material as fission proceeds. For low efficiencies, to which most of the other approximations made are applicable, the depletion is not significant and can be neglected. Moreover, no allowance has been made for the inertial effect of the tamper on the efficiency. For the present purpose, which is to obtain a qualitative guide to some of the factors determining the efficiency, this can also be ignored. Hence, replacing the quantity $1/(\gamma - 1)\epsilon$ by a constant, K, equation (2.20) can be written as

$$\phi \approx KR^2\alpha^2\delta \tag{2.21}$$

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which is a simplified version of the Bethe-Feynman formula. The efficiency of a fission weapon is seen to depend on the factors R, α, and δ.

2.36 Since the efficiency of a fission weapon may be expected to increase as R^2, it would be advantageous for the core to be large at the time of the initiation of the fission chain. One way in which this can be achieved in practice, e.g., in a gun-type weapon, is to bring together subcritical masses which are designed to contain a large total mass of fissile material. Thus, for a given compression or, especially, for no compression, the efficiency would be expected to be greater the larger the mass of the assembled core.

2.37 In general, the most important factor in determining the efficiency of a fission weapon is α; as seen in §2.16, this increases in proportion to the compression. The efficiency, according to equation (2.21), will thus be related, approximately at least, to η^2 (or to $\eta^{1.7}$ if the effect of tamper compression is taken into account). In addition, although of lesser significance, the effect of compression on δ must be taken into account; the more highly compressed the core material at the time of initiation (or at explosion time), the farther will be the distance the core surface must travel during the expansion phase before the supercritical system becomes subcritical. Increased compression should thus result in a marked gain in the efficiency of a fission weapon. It is this fact which is largely responsible for the much higher efficiencies of implosion systems than of gun-type devices.

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2.38 The effect of increasing compression in a simple (unboosted) implosion system is indicated by the data in Table 2.1 which are based partly on experimental observations and

Table 2.1— EFFECT OF COMPRESSION ON EFFICIENCY

Average Compression		Efficiency
Core	Tamper	(Percent)
[redacted]		

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partly on calculation [redacted] DOE 6(3)

The attainment of high compression has been an important objective in fission weapon design. In the earliest (solid-core) devices the improvement in efficiency was the main purpose. In more recent (hollow-core boosted) weapons, however, the principal objective is to make possible the design of compact systems in which both the high explosive (§1.42) and the fissile material have low masses. The number of crits at maximum compression is not large, so that α is relatively small before boosting. The initial efficiency of the fission chain is, therefore, also small but the total yield is greatly increased by the boosting.

INITIATION TIME AND PREINITIATION

Unboosted Implosion Weapons

2.39 The time at which the fission chain is initiated is of importance in determining the efficiency of a weapon [redacted] DOE 6(3)

[redacted] By this time the fissile core would be highly supercritical [redacted] DOE 6(3)

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[redacted] DOE b(3)

2.40 The avoidance of preinitiation was therefore an important aspect of the design of simple fission weapons. The neutron sources which served as initiators were constructed so as to produce a burst of neutrons as close as possible to the optimum time, and the neutron background from the fissile material was maintained within reasonable bounds. In all-plutonium cores, relatively clean (20 ngs) material was used and dirtier plutonium was employed only in composite cores which contained oralloy in addition, with the latter in excess. Such a utilization of fissile material was desirable in any event, for reasons given in §3.21 et seq.

2.41 The behavior of the solid core in an unboosted implosion weapon is somewhat as follows. [redacted] DOE b(3)

[redacted] At first critical, α is zero and it increases steadily as compression of the core proceeds. Just before maximum compression, when α is approaching its maximum value, neutrons are injected into the highly supercritical system. The divergent fission chain is initiated and energy is released. [redacted] DOE b(3)

[redacted] DOE b(3)

This condition is referred to as "second critical" (Fig. 2.2). Both the neutron density and the rate of the fission reaction are now at a maximum. Beyond second critical, α becomes negative and the neutron density decreases, in accordance with equation (2.6). Although a self-sustaining chain is no longer possible, considerable amounts of energy are produced by the convergent fission chains in the subcritical system.

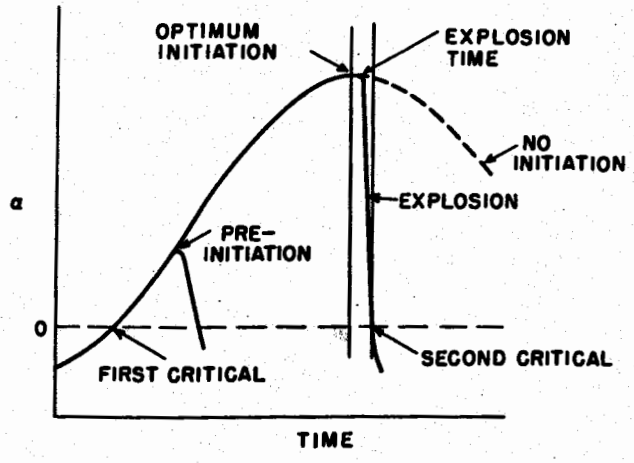


Figure 2.2

Boosted Implosion Systems

2.42 In modern boosted, implosion-type fission weapons, the situation is quite different from that described above. The cores are hollow, subcritical shells which contain the deuterium-tritium boosting gas. [redacted] DOE b(3)

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Gun-Type Weapons

2.45 In a gun-type weapon, the lack of compression makes it desirable for initiation to take place at or close to the time when assembly [redacted] DOE 6(3) Consequently, although plutonium-239 with an appreciable proportion of plutonium-240 could be used in implosion systems, even of the solid-core, unboosted type, it is unsuitable for gun-assembly devices, as the calculations given below will show.

2.46 Apart from the possible presence of a "flood" of neutrons, e.g., as the result of the explosion of another nuclear weapon in the vicinity of a given weapon, the chief sources of background neutrons, which could cause preinitiation in a gun-assembly weapon, are spontaneous fission and (α,n) reactions with light elements. In uranium-235 (oralloy) the rate of spontaneous fission is relatively small but (α,n) reactions with light-element impurities could produce an appreciable neutron background. [redacted] DOE 6(3)

2.47 Let P_1 be the probability that a background neutron will be available in the fissile material during the period that it is supercritical, i.e., in the preinitiation period, and let P_2 be the probability that this neutron will be able to start a fission chain. The preinitiation probability, P, is then given by

$$P = 1 - e^{P_1 P_2}$$
$$\approx P_1 P_2 \qquad (2.22)$$

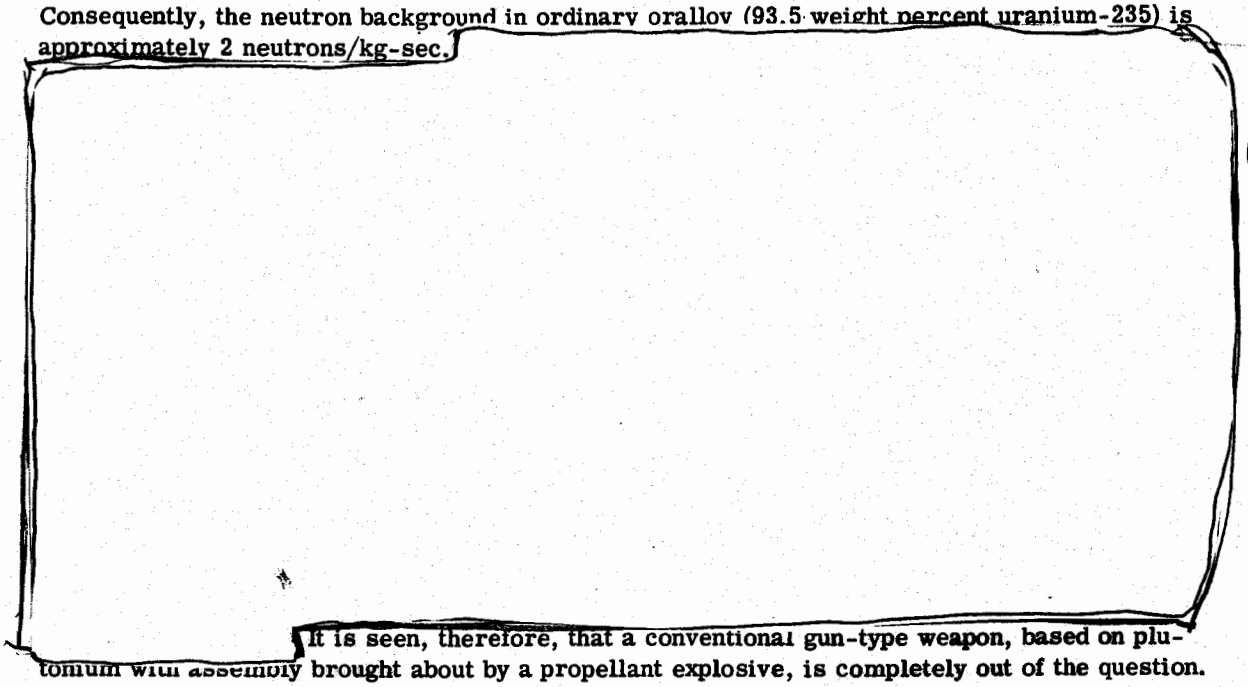
the approximate form being applicable when P_1P_2 is small, as it is in cases of interest. Actually P_2 is a function of time and both P_1 and P_2 depend, to some extent, on the position of the neutron and on other factors. For the present purpose, however, which is to draw general conclusions only, specific values will be assigned to P_1 and P_2. A background neutron entering a fissile assembly may escape altogether without being absorbed, or it may be captured in a nonfission reaction, or it may initiate a fission chain. Although the probabilities of these three processes are by no means equal, it is sufficient to postulate here that P_2 has a constant average value of 0.3 over the preinitiation period. Hence, for the purpose of making rough estimates, equation (2.22) may be written as

$$P \approx 0.3\, P_1 \qquad (2.23)$$

[redacted] DOE 6(3)

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2.48 As a result of spontaneous fission, uranium-235 emits, on the average about 0.85 neutron per kilogram per sec, whereas uranium-238 produces roughly 17 neutrons/kg-sec. Consequently, the neutron background in ordinary orallov (93.5 weight percent uranium-235) is approximately 2 neutrons/kg-sec.

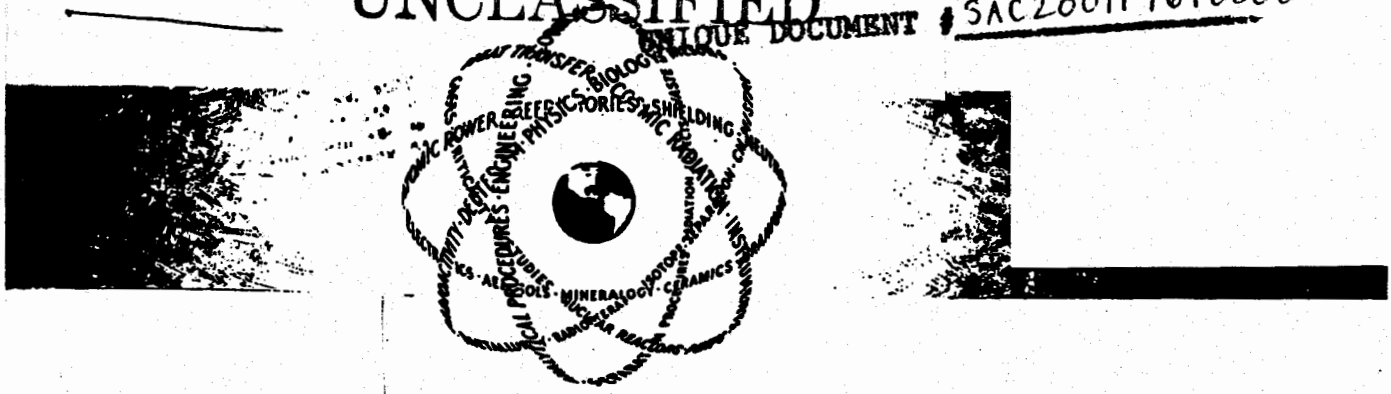


DOE 6(3)

It is seen, therefore, that a conventional gun-type weapon, based on plutonium with assembly brought about by a propellant explosive, is completely out of the question. It was the realization of this fact, when plutonium became available, that led to the development of implosion systems (§1.39).

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By
Samuel Glasstone

March 1963
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By

Samuel Glasstone

March 1963

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In preparing this report, I have received invaluable assistance from members of the Lawrence Radiation Laboratory (Livermore), Los Alamos Scientific Laboratory, Defense Atomic Support Agency (Headquarters and Field Command), the Sandia Corporation, and the AEC Division of Military Application. Unfortunately, it is not possible to list the names of all those individuals who contributed either by providing information or by reviewing the draft manuscript or both. However, I wish to acknowledge my great indebtedness to them, for without their help this report could not have been produced. My special thanks are due to Lawrence S. Germain for his effective coordination of the contributions from LRL, Livermore.

S. G.

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1.33 The procedure described above can be used to determine critical masses for both tamped (reflected) or untamped assemblies. It can also be applied to actual mockups of fission weapons. Some of the components, e.g., fissile substances, are the same as would be used in the weapon, whereas others, e.g., high explosive, would be simulated by other materials with similar neutronic properties.

1.34 Under precisely specified conditions, and for a given core material, there is a definite mass that is just critical; this is called a "crit." The critical masses of spheres of metallic uranium-235 (93.2 weight percent enrichment) and of the alpha- and delta-phases of plutonium-239 for fast-neutron fission are given in Table 1.2. Values are quoted for bare, i.e., untamped spheres, as well as for spheres with tampers of [redacted] beryllium, respectively. The effect of the neutronic tamper in reducing the critical mass is very striking. It will be noted, too, in accordance with remarks made earlier, that the critical mass of delta-plutonium is larger than that of the alpha form, whereas both are smaller than the critical mass of uranium-235.

DOE b(3)

FISSION WEAPONS

Gun Method of Assembly

1.35 As long as a mass of fissile material is less than the critical value for the existing conditions, that is to say, provided the system is subcritical, there is no danger of a divergent, or even a stationary, chain reaction. But, if energy is to be released in a nuclear explosion, the system must be made critical and, in fact, highly supercritical, as will be seen shortly. There are two general ways utilized in weapons whereby a subcritical system of fissile material is rapidly converted into one that is supercritical.

1.36 The first may be referred to as the gun method of assembly. Two portions of material of subcritical size are brought together very rapidly, so that the combined mass is supercritical. If a burst of neutrons is then introduced, a divergent fission chain is initiated and a rapid release of energy occurs in a very short time. This is the principle used in the so-called "gun-type" weapons: one [redacted] The name gun-type originates from the fact that in devices of this kind the two pieces of fissile material, [redacted] are located near opposite ends of a gun barrel.*

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1.37 Although the gun assembly method for attaining criticality is satisfactory when uranium-235 is the fissile material, it has a serious drawback when plutonium-239 is used. This arises from the presence of the higher isotope, plutonium-240. Because of the way it is produced (§1.53), plutonium-239 is invariably associated with a certain proportion—generally from about 2 to 7 percent—of the higher isotope, plutonium-240. The latter happens to have a high probability for undergoing spontaneous fission, i.e., without the intervention of neutrons. The spontaneous fission rate of plutonium-240 is, in fact, about 440 fissions per second per gram. Since nearly three neutrons are liberated per fission, this means that 1 gram of plutonium-240 emits well over 1000 neutrons per second. [redacted]

DOE b(3)

1.38 An efficient use of the fissile material in a simple gun-type weapon requires that the chain reaction be initiated by neutrons only when the assembly has attained its maximum criticality. [redacted] the considerable neutron background, arising from the presence of plutonium-240, may result in initiation of a self-sustaining chain reaction as soon as the assembly becomes just critical. If this occurs, there

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*It is purely a coincidence that in most nuclear artillery shells the gun type of assembly is used. [redacted] There is, however, another type of artillery shell which does not employ gun assembly (§4.37).

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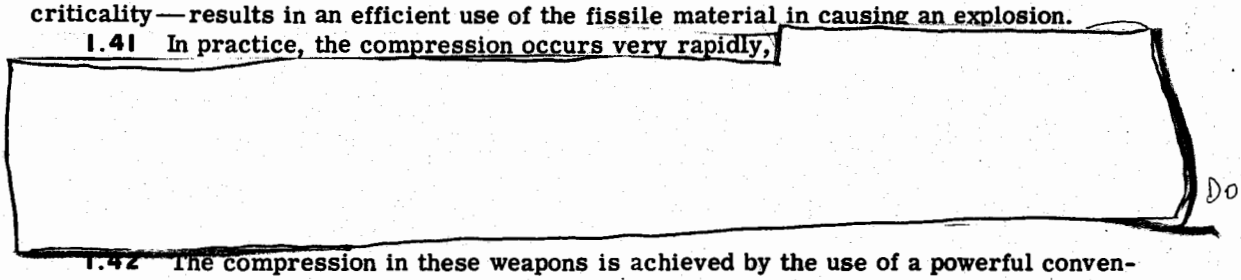
will be little or no explosion, since the neutron density will not increase rapidly and energy, resulting from fission, will not be produced fast enough; the reasons for such behavior will be apparent later. On the other hand, if uranium-235 is used in a gun-type weapon, the neutron background is very small and there is little probability of premature initiation, or "preinitiation," as it is called, immediately upon the system becoming critical. When maximum supercriticality is attained, neutrons are introduced deliberately from a suitable source to initiate the fission chain reaction. In this way, the optimum efficiency can be realized in the use of the fissile material.

Compression Method (Implosion Weapon)

1.39 Because of the probability of preinitiation, and low efficiency, of a gun-assembly weapon using plutonium-239, an alternative method for attaining criticality (or supercriticality) was developed, based on the compression of the subcritical fissile mass. This procedure turned out to be so successful and gave so much better efficiency that the gun-type of assembly has been utilized only in a relatively few weapons for special purposes, e.g., in artillery-fired shells and in rugged, impact-resistant bombs designed to penetrate some distance into the ground before exploding. Apart from these particular cases, the compression method is invariably used to attain supercriticality in fission weapons.

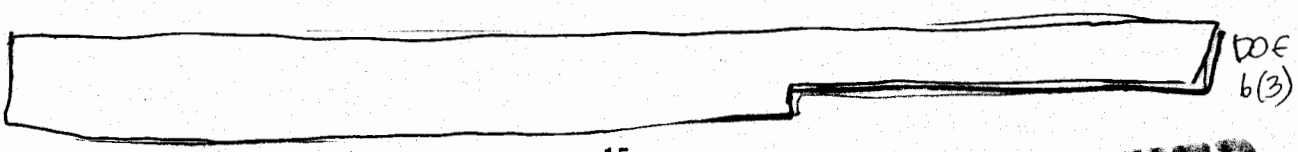
1.40 The principle of the method is that if a mass of fissile material is compressed, the rate of production of neutrons by fission in the subcritical state is essentially unchanged, since it depends mainly on the number of nuclei present. Actually, there will be some increase in the neutron production in convergent chains. On the other hand, the number of neutrons lost by escape is decreased as a result of compression because of the smaller surface area of the given mass. Consequently, a quantity of material which is subcritical in the normal state can become supercritical when compressed. The introduction of neutrons to initiate the fission chain at (or close to) the time of maximum compression—and, hence, of maximum supercriticality—results in an efficient use of the fissile material in causing an explosion.

1.41 In practice, the compression occurs very rapidly,



1.42 The compression in these weapons is achieved by the use of a powerful conventional (chemical) high explosive which surrounds the core of fissile material. By the use of explosive charges of special design much of the energy of the explosion is directed inward, thereby causing the material in the interior to be compressed in a spherically symmetric manner. It is for this reason that the term "implosion" is applied to weapons of this type.

1.43 An approximate derivation of the relationship between the degree of compression and the critical mass of fissile material is the following. In accordance with the definition given in §1.27, footnote, the total mean free path of a neutron is the average (crow-flight) distance it travels before it interacts in any way with a nucleus. The proportion of neutrons which do not interact but escape from the system may be expected to be determined by the ratio of the dimensions, e.g., the radius of a sphere, to the mean free path. It may be concluded, therefore, that for a given fissile (core) material, under specified conditions, the critical radius should be approximately proportional to the neutron mean free path; thus, if R_c is the critical radius and λ is the mean free path in the material,



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$$R_c \propto \lambda \tag{1.6}$$

1.44 The greater the probability of the interaction of a neutron with a nucleus, the smaller will be the distance the neutron travels before interacting. Hence, the neutron mean free path is related inversely to its interaction probability. This probability is proportional to the number of fissile nuclei per unit volume, and hence to the density; if ρ is the density of the core material, then

$$\lambda \propto \frac{1}{\rho} \tag{1.7}$$

It follows therefore from equations (1.6) and (1.7) that

$$R_c \propto \frac{1}{\rho} \tag{1.8}$$

1.45 The critical mass, M_c, is equal to the product of the critical volume, which is $\frac{4}{3}\pi R_c^3$, and the density of the fissile material; hence,

$$M_c = \frac{4}{3}\pi R_c^3 \rho$$

Upon substituting equation (1.8) for R_c, it is seen that

$$M_c \propto \frac{1}{\rho^2} \tag{1.9}$$

The density of the material is dependent upon the degree of compression; thus, if η is the compression ratio, i.e., the ratio of the volume before to that after compression, then

$$\rho \propto \eta$$

and substitution in equation (1.9) leads to the result

$$M_c \propto \frac{1}{\eta^2} \tag{1.10}$$

The critical mass of a given fissile material, under specified conditions, is thus inversely proportional to the square of the compression ratio. The proportionality constant is readily derived by writing M_{c0} for the critical mass of the uncompressed material, i.e., when $\eta = 1$. It follows then from equation (1.10) that

$$M_c = \frac{M_{c0}}{\eta^2} \tag{1.11}$$

1.46 An alternative way of stating this result is in terms of the number of crits (or critical masses), C, present in the compressed core. If M is the actual mass of fissile material, the number of crits in the compressed state is defined by

$$C = \frac{M}{M_c}$$

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Combination with equation (1.11) then yields

$$C = \frac{M\eta^2}{M_{c0}} = C_0\eta^2 \qquad (1.12)$$

where M/M_{c0} has been replaced by C_0, the number of crits before compression.

DOE 6(3)

The introduction of neutrons into this highly supercritical system resulting from compression will cause a very rapidly divergent fission chain reaction to develop. In these circumstances there is very efficient use of the fissile material for the release of energy. It is the high degree of supercriticality (and increased efficiency) attainable by compression that constitutes the great advantage of implosion-type weapons over those of the gun type.

1.47 Strictly speaking, the relationship of the number of crits to the square of the compression holds only for a bare core. For a tamped core, a more correct form of equation (1.12) is

$$C = C_0\eta_c^{1.2}\eta_t^{0.8}$$

where η_c is the compression of the core and η_t is that of the tamper. Since the tamper is generally compressed less than the core, a good approximation for weapons is to write

$$C = C_0\eta_c^{1.7}$$

The effect of compression is still substantial, although not as large as is implied by equation (1.12).

Fusion Reactions in Fission Weapons

1.48 It was stated in §1.2 that the large-scale release of energy in weapons is possible by making use of fusion reactions in which two very light nuclei combine (or fuse) together to form particles of greater mass. However, apart from the application of nuclear fusion reactions as a source of energy, described in Chapter 7, certain fusion processes are important in the design of fission weapons for another reason. The significance of these reactions does not lie in the energy released but in the neutrons which are produced. Three fusion reactions, involving the less common isotopes of hydrogen, namely, deuterium (D^2) and tritium (T^3), are of interest in this connection. Two of these reactions are between pairs of deuterium nuclei (deuterons) only, i.e.,

$$_1D^2 + {}_1D^2 \rightarrow {}_0n^1 + {}_2He^3$$

and

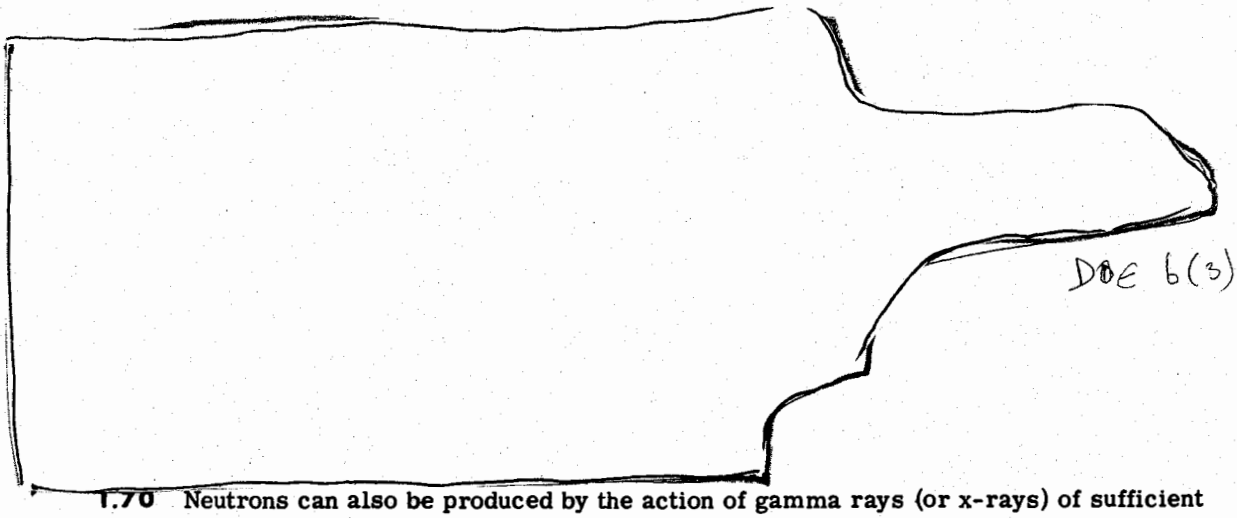
$$_1D^2 + {}_1D^2 \rightarrow {}_1H^1 + {}_1T^3$$

which take place at about the same rate, and the third is a much more rapid interaction between a deuteron and a tritium nucleus (triton), i.e.,

$$_1D^2 + {}_1T^3 \rightarrow {}_0n^1 + {}_2He^4$$

1.49 It is seen that when two deuterons interact, a neutron is formed in one case and a triton in the other; the triton then readily reacts with a deuteron to produce another neutron. Both deuteron-deuteron (D-D) and deuteron-triton (D-T) reactions are employed to provide

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1.70 Neutrons can also be produced by the action of gamma rays (or x-rays) of sufficient energy on various nuclei; these processes are referred to as photoneutron or (γ,n) reactions. Since the average binding energy of a nucleon in a nucleus is about 8 Mev in many cases (Fig. 1.1), a photon of this energy will eject a neutron from most nuclei. This fact was utilized in an experimental device for initiating the fission chain in nuclear weapons (§5.34).

1.71 In the great majority of weapons of recent design the neutrons required for initiation are produced by the fusion reactions described in §1.48. The procedures involve either the D-D or D-T reactions at high temperatures (thermonuclear reactions) or the interaction of accelerated tritons with a deuterium target (electronuclear reactions). The methods used for achieving these processes in weapons are described in Chapter 5.

Production of Deuterium and Tritium

1.72 Deuterium oxide (heavy water) is present to the extent of about one molecule in 6500, i.e., 0.015 mole percent, in ordinary water. In spite of this very small proportion, concentration of the deuterium in water is not too difficult, and heavy water of about 99.75 percent purity, i.e., 99.75 mole percent D_2O, is now produced on a large scale.

1.73 Three main processes are used to separate the two hydrogen isotopes in water; these are (a) isotopic (or chemical) exchange, (b) distillation, and (c) electrolysis. Several isotope exchange processes have been considered but the most satisfactory appears to be one involving reaction between hydrogen sulfide gas and liquid water. The exchange reaction results in a relatively higher proportion of deuterium in the liquid phase than in the gas. By utilizing a countercurrent flow of gas and liquid in several stages, in a system operating at two different temperatures, considerable enrichment in deuterium can be achieved in the liquid.

1.74 The distillation method for separating the isotopes of hydrogen depends on the fact that heavy water (D_2O) has a slightly higher boiling point, i.e., slightly lower vapor pressure, than light water (H_2O). Consequently, a partial separation can be achieved by fractional distillation, preferably under reduced pressure.

1.75 When an acid or alkaline aqueous solution is electrolyzed, the hydrogen gas liberated at the cathode contains relatively more of the lighter isotope (H_2) than does the residual water. By repeated electrolysis in stages, heavy water of a high degree of purity can be obtained.

1.76 Each of the three foregoing procedures has certain advantages under appropriate conditions. Hence, in the production of heavy water in quantity, ordinary water is first partially enriched in deuterium by the isotopic exchange process with hydrogen sulfide. The deuterium is further concentrated by fractional distillation of the enriched water under reduced pressure, and then it is brought up to 99.75 percent purity by electrolysis. Deuterium gas can be released from heavy water by any of the familiar chemical processes used to prepare hydrogen gas. It can then be very simply converted into any compound that may be required, e.g., uranium deuteride (UD_3) or lithium deuteride (LiD), for weapons applications.

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1.77 The third isotope of hydrogen, i.e., tritium, is a radioactive beta emitter, with a half-life of 12·26 years. It is found in natural waters to an insignificant extent only and the cost of extraction would be prohibitive. Consequently, tritium is produced by nuclear reactions resulting from the exposure of lithium (as a suitable compound) to neutrons in a reactor. The less abundant lithium-6 isotope, present to the extent of 7 atomic percent in natural lithium, readily captures slow neutrons and undergoes the (n,α) reaction

$$_3Li^6 + _0n^1 \rightarrow _2He^4 + _1T^3$$

with the formation of tritium. The more common isotope, lithium-7, reacts with fast neutrons to some extent and this process also leads to the production of tritium; thus,

$$_3Li^7 + _0n^1 \rightarrow _2He^4 + _1T^3 + _0n^1$$

1.78 After irradiation by neutrons for a length of time, the lithium compound is removed from the reactor and the gases, consisting mainly of tritium and helium, with other hydrogen isotopes as impurities, are separated from the residual solid. Purification is achieved by a gaseous diffusion process. Compounds of tritium can be prepared from the gas by reactions similar to those employed for deuterium and ordinary (light) hydrogen.

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AN INTRODUCTION TO NUCLEAR WEAPONS (U)

By Samuel Glasstone and
Leslie M. Redman

June 1972

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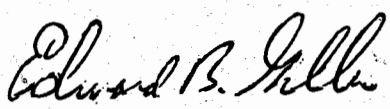
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FOREWORD

While this revision of WASH-1037 and the original issuance have been published as Headquarters, U. S. Atomic Energy Commission documents, they have as their genesis two 1954 Los Alamos Scientific Laboratory reports, LA 1632 and LA 1633, both entitled "Weapons Activities of LASL." We are indebted to LASL for these early reports. Although the previous LA and WASH reports received extensive use as basic handbooks on the principles of nuclear weapons development and technology, they were not to be considered as technical guides for designing weapons. Similarly, this revision of WASH-1037 is not to serve as such a guide.

In the preparation of this document, Dr. Samuel Glasstone has reviewed, coordinated, and edited data provided by members of the Los Alamos Scientific Laboratory, the Lawrence Livermore Laboratory, the Sandia Laboratories, and the Defense Nuclear Agency. The exceptional cooperation of these organizations and the outstanding work of Dr. Glasstone have permitted the Atomic Energy Commission to publish this revision to WASH-1037. Further, we wish to recognize the very significant contributions of Dr. Leslie M. Redman in the preparation of this issuance.

This publication contains highly sensitive nuclear weapon design information of significance to our national defense and security. Viewers are enjoined to ensure its proper security protection at all times.



Edward B. Giller
Major General, USAF
Assistant General Manager
for Military Application
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DOE (L3)

PREFACE

The overall design of a nuclear weapon is a complex operation involving a cooperative effort among mathematicians, scientists, and engineers in several areas of specialization. In spite of the complexity of these weapons, their design and operation are based on certain fundamental physical principles. One of the purposes of this report is to provide a description of these principles in fairly elementary terms. The mathematical aspects of weapon design have been omitted or oversimplified, since the emphasis here is placed on the physical phenomena rather than on the mathematical techniques used in treating them.

Another objective is to describe how the ideas used in weapons design have changed over the years. The earliest atomic bombs weighed some 8000 pounds and gave an explosive energy yield in the vicinity of 20 kilotons TNT equivalent. [redacted] DOE 6(3)

A semihistorical approach is used to show how such improvements in efficiency have been attained and indications are given of new directions in which further developments appear possible. It will be apparent that advances in weapons design have been continuous in the past and may be expected to be so in the future.

In preparing this report, we have received invaluable assistance from members of the Los Alamos Scientific Laboratory, Lawrence Livermore Laboratory, Sandia Laboratories (Albuquerque and Livermore), the Defense Nuclear Agency (Headquarters and Field Command), and the AEC Division of Military Application. To all the people who helped us by supplying information and/or providing constructive reviews of the draft material, we wish to express our great indebtedness.

Samuel Glasstone
Leslie M. Redman

energy. The results of estimates based on experimental measurements are given in Table 1.1 of the average

Table 1.1 NEUTRONS RELEASED PER FISSION

Nuclide	Neutron Energy		
	~0 MeV	0.5 MeV	14 MeV
Uranium-235	2.43	2.49	4.1
Plutonium-239	2.80	2.85	4.9
Uranium-233	2.45	2.51	4.2

number, ν, of neutrons produced per fission caused by (*a*) slow neutrons, i.e., neutrons of essentially zero energy, (*b*) neutrons of about 0.5-MeV energy, which is roughly the average energy of the neutrons which maintain the chain in a simple fission weapon, and (*c*) neutrons of 14-MeV energy which contribute greatly to the fission energy of boosted and many two-stage devices (Chapters 6 and 7).

1.13 The neutrons emitted in fission fall into two categories, namely, prompt neutrons and delayed neutrons. The former are all released within something like 10^{-14} sec of the fission process, but the latter continue to be emitted for a few minutes. For uranium-235 fission, the prompt neutrons constitute 99.35 percent of the total fission neutrons and for plutonium-239 they represent about 99.75 percent. Because the time scale in nuclear explosions is very short, delayed neutrons play essentially no part in the fission chain reaction. In reactors for the controlled release of nuclear energy, however, these neutrons are of great significance.

Fission Energy

1.14 The rough estimate made earlier indicated that about 200 MeV of energy are produced per nucleus undergoing fission. More precise calculations, based on nuclear masses, and experimental measurements have shown that this is a good approximation for both uranium-235 and plutonium-239. The atomic mass in grams, i.e., 235 grams of uranium-235, contains 6.02×10^{23} nuclei, and the complete fission of this amount of uranium-235 would yield $6.02 \times 10^{23} \times 200 = 1.20 \times 10^{26}$ MeV or 1.93×10^{20} erg, since 1 MeV is equal to 1.60×10^{-6} erg. Making use of the fact that 1 calorie is equivalent to 4.18×10^{7} ergs, it can be readily shown that complete fission of all the nuclei in 1 kilogram of fissile material would result in a total energy release of 2.0×10^{13} calories.

1.15 Only part of the energy of fission is immediately available in a nuclear explosion, since most of the radioactive decay energy of the fission products is released over a long period of time. It is usually accepted that about 90 percent of the fission energy contributes to the explosion, so that in a weapon the fission of 1 kilogram of material would produce explosive energy of about 1.8×10^{13} calories. The energy liberated in the explosion of 1 ton of TNT is taken to be 10^{9} calories (or 4.18×10^{16} ergs), and so 1 kilogram of fissile (or fissionable) material is equivalent in explosive power to 18,000 tons, i.e., 18 kilotons (or 18 kt) of TNT. From these results it is readily found that complete fission of 0.056 kg (or 56 g) or of 1.45×10^{23} nuclei of fissile material produces the equivalent of 1 kt of TNT of explosive energy. In other words, the energy per fission is about 7.0×10^{-24} kt TNT equivalent.* In stating the energy yields (or, in brief, the yields) of nuclear weapons, the basic unit, for very low yields, is the ton, with the kiloton (or 1,000 tons), i.e., 1 kt, and the megaton (or 1,000,000 tons), i.e., 1 Mt, of TNT equivalent being used for higher yields.

THE FISSION CHAIN REACTION

Condition for Chain Reaction: Critical Size

1.16 The condition for a self-sustaining fission chain reaction is that, on the average, the neutrons released in one act of fission shall cause (at least) one subsequent fission. Since the average number of neutrons produced in an act of fission is greater than two (see Table 1.1), it would appear, at first sight, that a chain reaction in uranium-235 or plutonium-239 would be inevitable. However, this is not so, because an appreciable proportion of the neutrons produced are lost in various ways. In a nuclear fission weapon, for example, an important source of loss is by leakage (or escape) of neutrons from the reacting material. Thus, many neutrons avoid being captured by a fissile nucleus by escaping from the system entirely. Some neutrons are also lost by parasitic capture, i.e., by capture in nonfission reactions of various kinds, either by the fissile species itself or by other nuclides which may be present.

*The energy per fission of uranium-235 is currently taken as 6.793×10^{-24} kt, i.e., 17.4 kt/kg; for plutonium-239 the values are 7.030×10^{-24} kt per fission and 17.7 kt/kg, respectively.

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1.17 The fraction of neutrons escaping from a system in which fission is occurring can be decreased by increasing the mass, i.e., by increasing the size at constant density of fissile material.* Since neutrons are produced by fission throughout the whole volume, whereas loss by escape takes place only from the exterior surface, it is evident that the escape probability will decrease as the volume-to-area ratio of the system is increased. This can be achieved, for a given geometry (shape), by increasing the dimensions of the fissile material at constant density.

1.18 In a very small mass of fissile material a self-sustaining chain reaction will not be possible under normal circumstances because of the large proportion of neutrons that escape. But as the size is increased (at constant density), the fraction of fission neutrons lost will decrease and ultimately a point is reached when one neutron will be available to carry on the fission chain for every neutron causing fission. The system is then said to be critical, and a self-sustaining chain reaction is just possible. If a system is smaller than the critical size (or mass), it is referred to as subcritical, and if larger, it is supercritical. In the latter case there are more neutrons available for fission at the end of any generation than were captured in fission reactions at the beginning of that generation. It will be seen shortly that the critical size (or mass) is dependent on the nature of the fissile material, its shape, and several other factors. For a given set of conditions, however, the critical size (or mass) has a definite value which can be determined by experiment or can sometimes be calculated.

Convergent, Stationary, and Divergent Chains

1.19 If ν is the average number of neutrons produced in each act of fission, for the existing neutron energy distribution (or neutron spectrum), and l is the number lost by escape and in other ways, e.g., by nonfission capture, then $\nu - l$ is the number of neutrons which can cause further fission; let this be represented by k, called the effective multiplication factor, i.e.,

$$k = \nu - l. \tag{1.4}$$

Thus, for every neutron causing fission in one generation, k neutrons will cause fission in the next generation. Alternatively, k may be defined as the ratio of the number of neutrons in any one generation to the number in the preceding generation. Hence, in accordance with the statements made above, k is less than unity for a subcritical system; in a critical system $k = 1$; and in a supercritical system k is greater than unity.

1.20 Suppose S neutrons are introduced into a mass of fissile material and cause fissions to occur; then kS neutrons will be present in the next generation, k^2S in the third, and so on. Since, for a subcritical system, $k < 1$, it is evident that as g, the number of generations, increases, k^gS will approach zero. In other words, the number of neutrons present will gradually decrease from one generation to the next, because more neutrons are lost in various ways than are being produced by fission. There is, consequently, a convergent or decaying chain which gradually dies out. For a system of critical size, $k = 1$ and then k^gS is always equal to S. The number of neutrons thus remains constant from generation to generation; this is referred to as a stationary chain. Finally, if $k > 1$, as is the case for a supercritical system, k^gS increases steadily. The fission chain is then said to be a divergent or expanding chain.

1.21 In the foregoing discussion no distinction has been made between the prompt and delayed fission neutrons. As stated earlier, however, it is essentially the prompt neutrons only which are significant in fission weapons. The effective critical size (or mass) of a weapon is thus determined by the availability of the prompt neutrons, without regard to those which are delayed. This situation is often described as prompt critical. Since more than 99 percent of fission neutrons are prompt, the neglect of the delayed neutrons has little effect on the value of ν. In other words, the data in Table 1.1 may be taken as being approximately applicable to weapons. Critical masses determined by experiment (§1.29) include the contribution of delayed neutrons, so that the prompt critical mass applicable to weapons is very slightly larger than the value measured in the laboratory. Again, the difference is small, although corrections can be applied if necessary.

Factors Affecting Critical Mass

1.22 The critical size (or mass) of a given fissile material depends on a number of factors, as mentioned earlier. For example, the shape (or geometry) of the system has an influence on criticality because of the variation in the ratio of volume to surface area. As seen in §1.17, this ratio determines the fraction of neutrons lost by leakage from the system. The optimum condition of minimum critical mass is obtained for a

*The reason for specifying constant density of fissile material will be apparent later (§1.40).

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sphere; this has the largest ratio of volume to area, so that the fraction of neutrons produced which escape from the system is less than for any other shape of the same mass. Thus, the critical mass of a sphere is less than for any other geometrical form of the given material.

[redacted]

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1.23 As far as the composition of the material is concerned, it is evident that the presence of impurities will increase the critical mass of the fissile species. Apart from the fact that the impurity may cause a loss of neutrons by parasitic capture, it adds area to the system, which increases the probability of neutron escape, without the compensating production of neutrons by fission in the increased volume. Similar considerations apply to the situation in which a given fissile substance, e.g., plutonium-239, exists in two or more allotropic forms with different densities. The less dense delta form of plutonium metal has a higher critical mass than the more dense alpha form because of the larger surface area for a given mass. The rate of neutron production by fission depends on the mass, i.e., the number of fissile nuclei, but the rate of loss by escape is greater for the delta-plutonium since the area is larger for the same mass.

1.24 The value of ν also affects the critical size. The larger the magnitude of ν, the smaller will be the critical size (or mass) under the same general conditions. If more neutrons are formed per fission, it will be possible to tolerate a somewhat larger loss and yet attain criticality. This is apparent from the fact that the critical condition is that $k = \nu - l = 1$, so that an increase in l can be compensated by an increase in ν. It is because both ν and the fast-neutron fission cross section of plutonium-239 are larger than for uranium-235 that the critical size of the former is less than that of the latter, under equivalent conditions. Since the densities of plutonium and uranium are not greatly different, the same relationship applies to the respective critical masses (see Table 1.2).

1.25 For a specified shape and composition, the size of a critical system can be decreased by surrounding it with a material which scatters some of the escaping neutrons back into the fissile core. By reducing the fraction of neutrons which escape completely, a smaller size (or mass) can become critical (§1.34). Such a scattering material, on account of its function, is sometimes referred to as a neutron reflector or as a neutron tamper.

1.26 In nuclear weapons, the fissile material is surrounded by a tamper or, more specifically, an inertial tamper, the mass of which delays expansion of the exploding material and permits a higher energy yield to be obtained from the system undergoing fission. This inertial tamper also serves as a neutron reflector or neutronic tamper. In some cases, however, the neutronic aspect is more important than the inertial character of the tamper.

1.27 As is to be expected, increasing the thickness of the tamper decreases the escape of neutrons and thus makes possible a smaller critical mass of the core of fissile material. However, it has been shown by calculations and verified experimentally that when the neutronic tamper thickness reaches a certain value, there is little more to be gained by a further increase of thickness (Fig. 1.2). Thus, when the thickness is about two neutron scattering mean free paths, the effectiveness in decreasing the critical mass is within a few percent of that for an infinitely thick tamper.* In natural uranium, which was at one time used as a

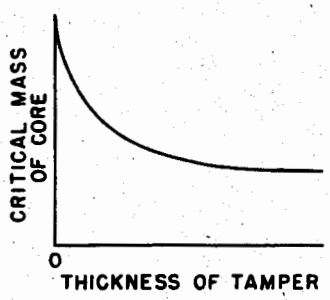


Figure 1.2

tamper, the scattering mean free path of fast (1 MeV) neutrons is about 4 cm, i.e., 1.6 in., in metal of normal density. The value is proportionately less in compressed uranium of higher density. In weapons of low mass, beryllium is a common tamper material; the scattering mean free path is somewhat longer than in uranium because of the lower density.

1.28 Another important factor which affects the critical size is the energy (or speed) of the neutrons causing fission. For several reasons, some of which will be explained later, nuclear weapons are designed so

*The scattering mean free path is the total distance a neutron travels before undergoing a scattering collision with a nucleus in the given tamper material.

[redacted] for fast-neutron fission are given in Table 1.2. Values are quoted for bare, i.e., untamped spheres, as well as for spheres with tampers of [redacted] The name gun-type originates from the fact that in devices of this kind the two pieces of fissile material [redacted] are located near opposite ends of a gun barrel.*

Table 1.2 CRITICAL MASSES OF SPHERES

Fissile Material	^{240}Pu (wt %)	Density (g/cm^3)	Critical mass (kg) Bare	[redacted] U	U	Be	Be
Uranium-235 (93.2 wt %)	-	18.8	52.5				
Plutonium-239 (α)	4.8	19.7	10.5				
Plutonium-239 (δ)*	4.8	15.8	16.6				
Plutonium-239 (δ)*	21	15.8	18.8				

*Contains ~1 wt % gallium

[redacted] beryllium, respectively. The effect of the neutronic tamper in reducing the critical mass is very striking. It will be noted, too, in accordance with remarks made earlier, that the critical mass of delta-plutonium is larger than that of the alpha form, whereas both are smaller than the critical mass of uranium-235.

FISSION WEAPONS

Gun Method of Assembly

1.35 As long as a mass of fissile material is less than the critical value for the existing conditions, that is to say, provided the system is subcritical, there is no danger of a divergent, or even a stationary, chain reaction. But, if energy is to be released in a nuclear explosion, the system must be made critical and, in fact, highly supercritical, as will be seen shortly. There are two general ways utilized in weapons whereby a subcritical system of fissile material is rapidly converted into one that is supercritical.

1.36 The first is generally referred to as the gun method of assembly. Two portions of material of subcritical size are brought together very rapidly, for reasons given below, so that the combined mass is supercritical. If a burst of neutrons is then introduced, a divergent fission chain is initiated and a rapid release of energy occurs in a very short time. This is the principle used in the so-called "gun-type" weapons: [redacted]

1.37 Although the gun assembly method for attaining criticality is satisfactory when uranium-235 is the fissile material, it has a serious drawback when plutonium-239 is used. This arises from the presence of the higher isotope, plutonium-240. Because of the way it is produced (§1.53), plutonium-239 is invariably associated with a certain proportion—generally from about 2 to 7 percent—of the higher isotope, plutonium-240. The latter happens to have a high probability for undergoing spontaneous fission, i.e., without the intervention of neutrons. The spontaneous fission rate of plutonium-240 is, in fact, about 440 fissions per second per gram. Since more than two neutrons are liberated per fission, on the average, this means that 1 gram of plutonium-240 emits over 1000 neutrons per second. [redacted]

1.38 An efficient use of the fissile material in a simple gun-type weapon requires that the chain reaction be initiated by neutrons only when the assembly has attained its maximum criticality. [redacted] the considerable neutron background, arising from the presence of plutonium-240, may result in initiation of a self-sustaining chain reaction as soon as the assembly becomes just critical. If this occurs, there will be little

*It is purely a coincidence that in most nuclear artillery shells the gun type of assembly is used [redacted] There is, however, another type of artillery shell which does not employ gun assembly (§4.23).

or no explosion, since the neutron density will not increase rapidly and energy, resulting from fission, will not be produced fast enough; the reasons for such behavior will be apparent later. On the other hand, uranium-235 has a small neutron background and therefore can be used in a gun-type weapon. If assembled rapidly enough, there is little probability of premature initiation, or "preinitiation," as it is called, immediately upon the system becoming critical. When maximum supercriticality is attained, neutrons are introduced deliberately from a suitable source to initiate the fission chain reaction. In this way, the optimum efficiency can be realized in the use of the fissile material.

Compression Method (Implosion Weapon)

1.39 Because of the probability of preinitiation, and low efficiency, of a gun-assembly weapon using plutonium-239, an alternative method for attaining criticality (or supercriticality) was developed, based on the compression of the subcritical fissile mass. This procedure turned out to be so successful and gave so much better efficiency that the gun type of assembly has been utilized only in a relatively few weapons for special purposes, e.g., in artillery-fired shells and in rugged, impact-resistant bombs designed to penetrate some distance into the ground before exploding. Apart from these particular cases, the compression method is invariably used to attain supercriticality in fission weapons.

1.40 The principle of the method is that if a mass of fissile material is compressed, the rate of production of neutrons by fission in the subcritical state is essentially unchanged, since it depends mainly on the number of nuclei present. Actually, there will be some increase in the neutron production in convergent chains. On the other hand, the number of neutrons lost by escape is decreased as a result of compression because of the smaller surface area of the given mass. Consequently, a quantity of material which is subcritical in the normal state can become supercritical when compressed. The introduction of neutrons to initiate the fission chain at (or close to) the time of maximum compression—and, hence, of maximum supercriticality—results in an efficient use of the fissile material in causing an explosion.

1.41 In practice, the compression occurs very rapidly.

[redacted]

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[redacted]

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1.42 The compression in these weapons is achieved by the use of a powerful conventional (chemical) high explosive which surrounds the core of fissile material. By the use of explosive charges of special design much of the energy of the explosion is directed inward, thereby causing the material in the interior to be compressed in a spherically symmetric manner. It is for this reason that the term "implosion" is applied to weapons of this type.

1.43 An approximate derivation of the relationship between the degree of compression and the critical mass of fissile material is the following.† The total mean free path of a neutron is the average distance it travels before it interacts in any way with a nucleus. The proportion of neutrons which do not interact but escape from the system may be expected to be determined by the ratio of the dimensions, e.g., the radius of a sphere, to the mean free path. It may be concluded, therefore, that for a given fissile (core) material, under specified conditions, the critical radius should be approximately proportional to the neutron mean free path; thus, if R_c is the critical radius and λ is the mean free path in the material,

$$R_c \propto \lambda. \tag{1.6}$$

1.44 The greater the probability of the interaction of a neutron with a nucleus, the smaller will be the distance the neutron travels before interacting. Hence, the neutron mean free path is related inversely to its interaction probability. This probability is proportional to the number of fissile nuclei per unit volume, and hence to the density; if ρ is the density of the core material, then

$$\lambda \propto \frac{1}{\rho}. \tag{1.7}$$

[redacted]

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†The purpose of the discussion in §1.43 through §1.47 is to provide a general basis for understanding the effect of compression on criticality. It is not intended to imply that the methods are currently used. At present, computer calculations, which can take many variables into consideration, are employed to derive criticality conditions. The term "crit" in §1.46 is now more or less obsolete in weapons calculations.

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It follows therefore from equations (1.6) and (1.7) that

$$R_c \propto \frac{1}{\rho}. \tag{1.8}$$

1.45 The critical mass, M_c, is equal to the product of the critical volume, which is $\frac{4}{3}\pi R_c^3$, and the density of the fissile material; hence,

$$M_c = \frac{4}{3}\pi R_c^3 \rho.$$

Upon substituting equation (1.8) for R_c, it is seen that

$$M_c \propto \frac{1}{\rho^2}. \tag{1.9}$$

The density of the material is dependent upon the degree of compression; thus, if η is the compression ratio, i.e., the ratio of the volume before to that after compression, then

$$\rho \propto \eta,$$

and substitution in equation (1.9) leads to the result

$$M_c \propto \frac{1}{\eta^2}. \tag{1.10}$$

The critical mass of a given fissile material, under specified conditions, is thus inversely proportional to the square of the compression ratio. The proportionality constant is readily derived by writing M_{c0} for the critical mass of the uncompressed material, i.e., when $\eta = 1$. It follows then from equation (1.10) that

$$M_c = \frac{M_{c0}}{\eta^2}. \tag{1.11}$$

1.46 An alternative way of stating this result is in terms of the number of "crits" (or critical masses), C, present in the compressed core. If M is the actual mass of fissile material, the number of crits in the compressed state is defined by

$$C = \frac{M}{M_c}.$$

Combination with equation (1.11) then yields

$$C = \frac{M\eta^2}{M_{c0}} = C_0\eta^2, \tag{1.12}$$

where M/M_{c0} has been replaced by C_0, the number of crits before compression.

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The introduction of neutrons into this highly supercritical system resulting from compression will cause a very rapidly divergent fission chain reaction to develop. In these circumstances there is very efficient use of the fissile material for the release of energy. It is the high degree of supercriticality (and increased efficiency) attainable by compression that constitutes the great advantage of implosion-type weapons over those of the gun type.

1.47 Strictly speaking, the relationship of the number of crits to the square of the compression holds only for a bare core. For a tamped core, a more correct form of equation (1.12) is

$$C = C_0\eta_c^{1.2}\eta_t^{0.8},$$

where η_c is the compression of the core and η_t is that of the tamper. Since the tamper is generally compressed less than the core, a good approximation for weapons is to write

$$C = C_0\eta_c^{1.7}.$$

The effect of compression is still substantial, although not as large as is implied by equation (1.12).

Fusion Reactions in Fission Weapons

1.48 It was stated in §1.02 that the large-scale release of energy in weapons is possible by making use of fusion reactions in which two very light nuclei combine (or fuse) together to form a nucleus of larger mass. However, apart from the application of nuclear fusion reactions as a source of energy, described in Chapter 7, certain fusion processes are important in the design of fission weapons for another reason. The significance of these reactions does not lie in the energy released but in the neutrons which are produced. Three fusion reactions, involving the less common isotopes of hydrogen, namely, deuterium ($^2_1$H or D) and tritium ($^3_1$H or T), are of interest in this connection. Two of these reactions are between pairs of deuterium nuclei (deuterons) only, i.e.,

$$^2_1\mathrm{H} + {}^2_1\mathrm{H} \rightarrow {}^1_0n + {}^3_2\mathrm{He} \text{ or } \mathrm{D} + \mathrm{D} \rightarrow n + {}^3\mathrm{He}$$

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and

$$^{2}_{1}H + ^{2}_{1}H \rightarrow ^{1}_{1}H + ^{3}_{1}H \text{ or } D + D \rightarrow H + T,$$

which take place at about the same rate, and the third is a much more rapid interaction between a deuteron and a tritium nucleus (triton), i.e.,

$$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{1}_{0}n + ^{4}_{2}He \text{ or } D + T \rightarrow n + ^{4}He.$$

1.49 In a mixture of deuterium and tritium, the main reaction is between a deuteron and a triton which results in the formation of a neutron as one of the products. In deuterium alone, a neutron is also a product in one of the deuteron-deuteron (D-D) reactions. In the other D-D reaction, a triton is formed and this readily reacts with a deuteron to produce another neutron. Both deuteron-deuteron (D-D) and deuteron-triton (D-T) reactions are employed to provide neutrons for initiating fission chains. In addition, the high-energy (14 MeV) neutrons liberated in the D-T reaction are used in many fission weapons to achieve what is known as "boosting." Neutrons from the D-T reaction are introduced at a late stage of the fission chain in order to maintain and enhance the progress of the fission reactions. There is a considerable increase in the energy released because of the greatly improved efficiency in utilization of the fissile material. The energy contributed under the circumstances by the D-T fusion reaction is, however, quite small in comparison with that from fission.

PRODUCTION OF WEAPONS MATERIALS

Uranium-235

1.50 The two important fissile materials, namely, uranium-235 and plutonium-239, are both produced from natural uranium but by entirely different procedures. Ordinary uranium contains about 0.7 percent of uranium-235, together with about 99.3 percent of uranium-238 and a trace (0.006 percent) of uranium-234. The proportion of uranium-235 is increased by a process involving diffusion or, more correctly, effusion through porous barriers of the vapor of uranium hexafluoride (UF_6) made from natural uranium. The hexafluoride of the lighter isotope diffuses more rapidly than does that of the heavier species, and by the use of several thousand diffusion stages enrichments of over 90 percent are obtained, i.e., the material produced contains over 90 percent of uranium-235. The most common product for weapons use consists of about 93.2 weight percent uranium-235, the remainder being mainly uranium-238 and a small proportion of uranium-234. This product is commonly known as "oralloy," the two initial letters standing for Oak Ridge, where the material was first made in quantity.*

[redacted] DOE b(3)

1.51 The highly enriched uranium hexafluoride obtained from the gaseous diffusion plant is converted into the tetrafluoride (UF_4) by reduction with hydrogen (mixed with some fluorine). The tetrafluoride, which is a solid with a high melting point (close to 1000°C), is mixed with calcium and heated in a closed steel vessel lined internally with a refractory material. The calcium reduces the uranium tetrafluoride to uranium metal which is separated from the slag of calcium fluoride. Volatile impurities are removed by heating the liquid metal in a vacuum and the resulting product is of a high degree of purity.

1.52 The residual material from the isotope separation (gaseous diffusion) plant consists of uranium hexafluoride which has been depleted in uranium-235. In other words, it contains more than the normal 99.3 percent of uranium-238. This is converted into uranium metal by a procedure similar to that described above. It is referred to as depleted uranium or, in the weapons program, as D-38, because at one time it contained 0.38 percent uranium-235, although greater depletion has been regularly achieved. At one time it was called Q-metal, but this name is not now in common use.

Plutonium-239

1.53 The element plutonium does not occur in nature, except in insignificant traces. Consequently, the plutonium-239 used in weapons is obtained artificially by a series of nuclear reactions resulting from exposure of uranium-238 to slow neutrons in a nuclear reactor. A nuclear reactor is a device in which a fission chain reaction is taking place in a controlled manner, as against the deliberately uncontrolled chain reaction in a weapon. If a material of low mass number, called a

*The "alloy" part of the name originated from the designation Tube Alloys Limited applied to the British wartime atomic energy project. Natural uranium metal was thus called "tuballoy," a term still in common use, and then oralloy was adopted for the material highly enriched in uranium-235.

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moderator, is present, in addition to fissile material, the fission neutrons are slowed down. Such a nuclear reactor is thus a good source of slow neutrons.

1.54 Uranium-238 nuclei capture slow neutrons quite readily to form a higher isotope, uranium-239, with the emission of gamma radiation; thus, the (n,γ) reaction

$$^{238}_{92}\mathrm{U} + ^{1}_{0}n \rightarrow ^{239}_{92}\mathrm{U} + \gamma$$

occurs, where the subscripts give the atomic numbers and the superscripts the mass numbers in each case; the neutron ($^{1}_{0}n$) has a charge (atomic number) of zero and a mass of unity. The uranium-239 produced by neutron capture is radioactive, with a half-life of 23 min, emitting a beta particle. Representing the latter by $^{0}_{-1}\beta$, since it carries a unit negative charge and has essentially no mass, the radioactive decay process may be written as

$$^{239}_{92}\mathrm{U} \rightarrow ^{0}_{-1}\beta + ^{239}_{93}\mathrm{Np},$$

the product being an isotope of mass number 239 of an element of atomic number 93. This element, called neptunium (Nn), is virtually nonexistent in nature.

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[redacted]

1.55 Neptunium-239 is also radioactive with a half-life of 2.3 days; it emits a beta particle according to the reaction

$$^{239}_{93}\mathrm{Np} \rightarrow ^{0}_{-1}\beta + ^{239}_{94}\mathrm{Pu},$$

so that the product has a mass number of 239 and an atomic number of 94. The name plutonium, symbol Pu, has been given to the element with this atomic number. The isotope plutonium-239 is an alpha-particle emitter with a fairly long half-life—about 24,000 years—so that it is relatively stable. It may be mentioned that the decay product of plutonium-239 is the fissile uranium-235, which has a half-life of about 7×10^8 years. Hence, as far as fission is concerned, plutonium-239 could be stored for thousands of years with only minor deterioration. The little deterioration which does occur arises mainly from the fact that the average number of neutrons, ν, produced by fission of uranium-235 is somewhat less than that from plutonium-239 (§ 1.12).

1.56 For the production of plutonium-239, natural uranium metal is used as the fuel material in a nuclear reactor with graphite (Hanford) or heavy water (Savannah River) as the moderator. The uranium-235 in the fuel sustains the fission chain reaction and produces neutrons, some of which are captured by the uranium-238 with the consequent formation of plutonium-239, as described above. After being in the reactor for an appropriate time, the "spent" fuel is removed, dissolved in nitric acid, and the plutonium is extracted from the solution by the use of certain organic solvents. It is then reextracted into a water medium to give an aqueous solution of the nitrate, from which the plutonium is precipitated either as the peroxide or the oxalate. The solid compound is separated and heated with a mixture of hydrogen fluoride gas and oxygen to obtain plutonium tetrafluoride (PuF_4). The latter is finally reduced to plutonium metal with calcium (plus iodine).

1.57 Metallic plutonium exists in six different allotropic forms between room temperature and the melting point (641°C). The temperature ranges over which the various forms (or phases) are stable are shown in Table 1.3. It is seen that alpha-plutonium, referred to in §§ 1.23 and 1.34, which has a density of about 19.8 g/cm³, is stable at ordinary temperatures. The high density is advantageous from certain weapon standpoints, since it permits attainment of criticality in a smaller mass than is possible with other forms of plutonium (cf. Table 1.2). On the other hand, alpha-plutonium is brittle and difficult to fabricate. Furthermore, the presence of certain impurities tends to stabilize the beta or delta phases to some extent,

Table 1.3 PROPERTIES OF SOLID PHASES OF PLUTONIUM

Phase	Stability range (°C)	Density (g/cm³)
Alpha (α)	Below 115	19.86 (25°C)
Beta (β)	115–~200	17.70 (190°)
Gamma (γ)	~200–310	17.14 (235°)
Delta (δ)	310–458	15.92 (320°)
Delta prime (δ')	458–480	16.0 (465°)
Epsilon (ϵ)	480–641 (m.p.)	16.51 (490°)

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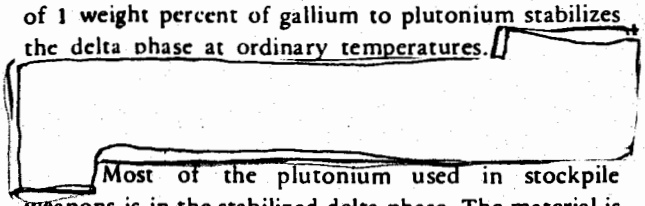
parts made of nominal alpha-plutonium are not dimensionally stable. However, if these impurities are avoided, the problem of dimensional instability does not arise at ambient temperatures.

1.58 Although delta-plutonium is normally stable in the temperature range of 310 to 458°C, the addition

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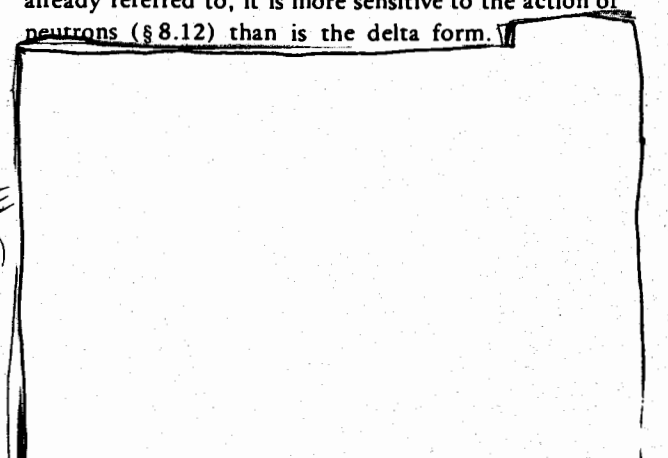
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of 1 weight percent of gallium to plutonium stabilizes the delta phase at ordinary temperatures.



Most of the plutonium used in stockpile weapons is in the stabilized delta phase. The material is much less brittle and easier to fabricate than alpha-plutonium; in fact delta-plutonium is said to resemble copper in this respect whereas the alpha-phase is more like cast iron. Delta-plutonium was used in the earliest implosion weapons because it could be fabricated more readily. It offered the additional advantage that its low density permitted the use of a larger mass of subcritical fissile material (Table 1.2), thereby making possible an increase in the total energy yield. This latter aspect of weapons design is, however, no longer significant.

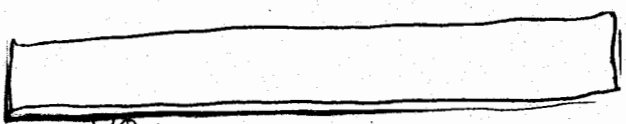
1.59 In order to minimize the critical mass and thus the overall weight of a weapon, it would be desirable to use plutonium of high density. Alpha plutonium has consequently been employed to some extent, but, in addition to the fabrication difficulty already referred to, it is more sensitive to the action of neutrons (§ 8.12) than is the delta form.



Plutonium-240 and -241

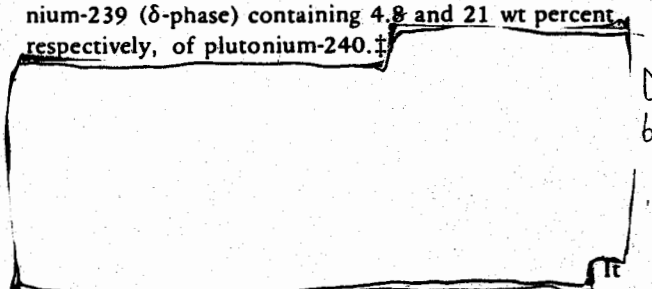
1.61 As the plutonium-239 accumulates in the reactor in which it is produced, it also captures neutrons, the rate of capture being proportional to the neutron density (or flux) in the reactor and to the concentration of plutonium-239 nuclei. The reaction which takes place is

$$^{239}_{94}\mathrm{Pu} + {}^{1}_{0}n \rightarrow {}^{240}_{94}\mathrm{Pu} + \gamma,$$



the product being plutonium-240, an alpha emitter of about 6600 years half-life. Because chemical processes are used for the extraction of plutonium from the spent reactor fuel, the two isotopes of this element are not separated from each other. Hence, plutonium-239 is always associated with a certain proportion of plutonium-240. Some of the latter is converted into plutonium-241 by neutron capture, but the amount of plutonium-240 (and plutonium-241) increases with both exposure time and the neutron density (or flux) in the reactor. In a production reactor, the practical limiting proportion of plutonium-240 is about 8 percent (~1 percent plutonium-241); it could go higher than this, as indeed it does in power reactors, but there would be a corresponding (and undesirable) loss of plutonium-239.

1.62 In a simple (unboosted) implosion type weapon, it is desirable that the plutonium-240 content be as small as possible for two reasons: (*a*) the high spontaneous fission rate of plutonium-240 causes a large neutron background (§ 1.37) which can result in the initiation of a fission chain before the optimum time, and (*b*) the fission of plutonium-240 requires neutrons of high energy and, in addition, the ν value is smaller than for plutonium-239 so that it acts, to some extent, as inert diluent.† Consequently, the presence of plutonium-240 increases the critical mass, as may be seen by comparing the values in Table 1.2 for plutonium-239 (δ-phase) containing 4.8 and 21 wt percent, respectively, of plutonium-240.‡



It should be noted that to obtain a product with a small proportion of plutonium-240, the uranium fuel elements can be permitted to remain in the reactor for only a short time before they are removed and processed for the extraction of plutonium. As a result, the smaller the plutonium-240 content, the higher the cost of the material produced.

†Fission of plutonium-240 exhibits an appreciable resonance for neutrons of about 1-eV energy. Otherwise, the cross sections are low except at high neutron energies, above about 0.5 MeV.

‡It is of interest that the critical mass of plutonium containing as much as 35 wt percent of plutonium-240 is still considerably less than that of uranium-235.

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1.63 In evaluating the cost of the plutonium in a weapon, it must be recognized that the higher the plutonium-240 content the smaller the cost per unit mass of plutonium-239, but the larger the mass required for criticality. The actual cost per crit, which is the important criterion, is thus determined by two opposing factors. The weapon cost first decreases and then increases as the proportion of plutonium-240 is increased. However, cost is not the only factor to be taken into account in the choice of weapon material. Other considerations are the effect of plutonium-240 on boosting (Chapter 6) and on "one-point" safety (Chapter 9). Although in principle, fission weapons could be designed to use materials with a much higher content of plutonium-240 (§ 2.72), the plutonium in current use for weapons contains roughly 6 percent of plutonium-240 (see Table 1.5). This is regarded as the best compromise at the present time, although it may be subject to change with circumstances.

1.64 For a production reactor of a given type, the plutonium-240 content of the material produced depends on the neutron density (or reactor power) and the exposure time. Consequently, the quality of plutonium was at one time described in terms of megawatt-days of exposure in the reactor per ton of uranium fuel, i.e., in MWD/T units. This unit is not very precise because the power of a reactor is not uniform throughout its volume; the plutonium-240 content corresponding to a given MWD/T value will often vary with the location of the fuel in the reactor. It also depends upon the characteristics of the production reactor, so that it is different for the Hanford (graphite moderated) and Savannah River (heavy-water moderated) reactor products (see Table 1.4). An alternative method for expressing quality is the number of grams of plutonium per ton of fuel removed for processing, generally indicated by *g*/T; the higher the *g*/T value the greater the plutonium-240 content. Because 1 MWD of reactor energy produces roughly 1 gram of plutonium, the values are approximately equal numerically in *g*/T and MWD/T units.

Table 1.4 CHARACTERISTICS OF PRODUCTION PLUTONIUM

MWD/T			
Hanford	Savannah River	Plutonium-240 (percent)	Neutrons/gram-sec (n/g/s)
800	1375	7.1	75
600	1000	5.6	58
400	630	3.85	40

1.65 The two foregoing methods of indicating the quality of plutonium have now been replaced by the actual statement of the weight percent of plutonium-240. Some of the older fission weapons required plutonium of low plutonium-240 content ("clean" plutonium); the purest material generally used contained about 1.5 percent of plutonium-240.

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1.66 Another way of expressing the amount of plutonium-240 is based on direct measurement of the rate of neutron emission from the material. These neutrons arise mainly from the spontaneous fission of plutonium-240. The result is expressed as the number of neutrons emitted per gram per second, abbreviated to n/g/s.* The n/g/s value is seen to be approximately 10.5 times the percentage of plutonium-240. The characteristics of three production materials from the Hanford and Savannah River plants with different plutonium-240 contents are given in Table 1.4.

1.67 Continued exposure in a nuclear reactor leads to the conversion of some plutonium-240 into plutonium-241 by neutron capture, as mentioned in § 1.61. Thus, "reactor grade" plutonium, produced in power reactors, may contain 10 percent or more of the latter isotope, together with about 15 percent of plutonium-240. The fission properties, i.e., cross sections and average number of neutrons per fission, of plutonium-241 are similar to those of plutonium-239, and it would consequently be equally effective for weapons purposes. Some consideration has thus been given to the possibility of utilizing reactor grade plutonium for weapons, especially since relatively large amounts of plutonium-240 can be tolerated, if necessary.

1.68 An interesting point in this connection arises from the radioactive beta-decay of plutonium-241 (half-life 13 years) to form americium-241.

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*The incorrect abbreviation "ngs" is often used in the weapons literature.

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If the plutonium were to be used in the alpha phase, however, the presence of a relatively large proportion of plutonium-241, which would decay to americium-241, could lead to a phase change to the delta form. The accompanying decrease in density would then result in dimensional instabilities. To test this point, a sample of alpha-plutonium containing 12.3 percent of plutonium-241 has been under observation since February 1964. A decrease in density from 19 to about 17.8 g/cm^3 occurred between 56 and 64 months, when the americium content was roughly 2.7 weight percent, but x-ray examination showed that the material still consisted entirely of the alpha phase. The significance of the results is uncertain and the observations are being continued.

Composition of Weapons Plutonium

1.69 In addition to plutonium-239 and -240, which are the main components, weapons-grade plutonium contains small quantities of isotopes of both higher and lower mass numbers. These are produced in a reactor by various neutron reactions either $(n,2n)$ or (n,γ). The average isotopic compositions of plutonium from Hanford and Savannah River plants reported in June 1968 are quoted in Table 1.5; these may be regarded as typical of current production.

Table 1.5 COMPOSITION OF WEAPONS-GRADE PLUTONIUM IN WEIGHT PERCENT

	Hanford	Savannah River
Plutonium-238	<0.05	<0.05
Plutonium-239	93.17	92.99
Plutonium-240	6.28	6.13
Plutonium-241	0.54	0.86
Plutonium-242	<0.05	<0.05

Possible Weapons Materials

1.70 Several fissile nuclides, with atomic number exceeding 94, are known, but they are of no practical value for weapons purposes because of their short half-lives. A region of stability has been predicted, theoretically, however, for very heavy species in the vicinity of those having "magic numbers" of both protons and neutrons, e.g., 114 protons and 184 neutrons, i.e., $^{298}_{114}$X, and 126 protons and 184 neutrons, i.e., $^{310}_{126}$X. Such nuclides might have half-lives up to 10^6 to 10^8 years, and would be expected to be capable of sustaining a fission chain with neutrons.

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Production of Neutrons

1.73 In a fission weapon, the chain reaction is initiated by the introduction of neutrons into a critical or supercritical system. Consequently, the general methods for producing neutrons in weapons will be reviewed here. One of the simplest procedures for obtaining neutrons is by the action of alpha particles on certain light elements, notably beryllium; processes of this kind are referred to as (α,n) reactions. Recalling that the alpha particle is actually a helium nucleus, the reaction is represented by

$$^4_2\mathrm{He} + ^9_4\mathrm{Be} \rightarrow ^{12}_6\mathrm{C} + ^1_0n.$$

1.74 A convenient source of alpha particles, which was used extensively at one time in fission weapons, is

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the radioelement polonium-210. This isotope has certain advantages, associated with corresponding drawbacks. It does not emit gamma rays, so that there is no neutron production by the (γ,n) reaction which might otherwise occur even when the polonium-210 and beryllium are separated in such a manner as to prevent access of alpha particles to the latter. Moreover, the polonium-210 is easy to produce by exposure of ordinary bismuth to neutrons in a nuclear reactor, when the (n,γ) reaction

$$^{209}_{83}\text{Bi} + ^{1}_{0}n \rightarrow ^{210}_{83}\text{Bi} + \gamma$$

takes place. The bismuth-210 is a beta emitter with a half-life of 5 days, so that it soon decays to form polonium-210; thus,

$$^{210}_{83}\text{Bi} \rightarrow ^{0}_{-1}\beta + ^{210}_{84}\text{Po}.$$

However, the production of polonium-210 in this manner means that fewer neutrons are available for the conversion of uranium-238 into plutonium-239.

1.75 As a result of the moderately short half-life of polonium-210—138.4 days—it emits alpha particles rapidly and a small quantity can thus provide a strong neutron source in conjunction with beryllium. But the short half-life is also a serious disadvantage, because the activity falls off relatively rapidly. In one year, the alpha activity, and hence the rate of neutron production, will have decreased to 18 percent and in two years to 2.6 percent of its initial value.

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1.79 Neutrons can also be produced by the action of gamma rays (or x rays) of sufficient energy on various nuclei; these processes are referred to as photoneutron or (γ,n) reactions. Since the average binding energy of a nucleon in a nucleus is about 8 MeV in many cases (Fig. 1.1), a photon of this energy will eject a neutron from most nuclei. This fact was utilized in an experimental device for initiating the fission chain in nuclear weapons (§ 5.25).

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1.80 In the great majority of weapons of recent design the neutrons required for initiation are produced by the fusion reactions described in § 1.48. The procedures involve either the D-D or D-T reactions at high temperatures (thermonuclear reactions) or the interaction of accelerated tritons with a deuterium target (electronuclear reactions). The methods used for achieving these processes in weapons are described in Chapter 5.

Production of Deuterium and Tritium

1.81 Deuterium (in the form of the mixed oxide, HDO) is present to the extent of about one atom to 6500 atoms of hydrogen, i.e., 0.015 atom percent, in ordinary water. In spite of this very small proportion, concentration of the deuterium in water is not too difficult, and heavy water of about 99.75 percent purity, i.e., 99.75 mole percent D_2O, is now produced on a large scale.

1.82 Three main processes are used to separate the two hydrogen isotopes in water; these are (*a*) isotopic (or chemical) exchange, (*b*) distillation, and (*c*) electrolysis. Several isotope exchange processes have been considered but the most satisfactory appears to be one involving reaction between hydrogen sulfide gas and liquid water. The exchange reaction results in a relatively higher proportion of deuterium in the liquid phase than in the gas. By utilizing a countercurrent flow of gas and liquid in several stages, in a system operating at two different temperatures, considerable enrichment in deuterium can be achieved in the liquid.

1.83 The distillation method for separating the isotopes of hydrogen depends on the fact that heavy water (D_2O) has a slightly higher boiling point, i.e., slightly lower vapor pressure, than light water (H_2O). Consequently, a partial separation can be achieved by fractional distillation, preferably under reduced pressure.

1.84 When an acid or alkaline aqueous solution is electrolyzed, the hydrogen gas liberated at the cathode contains relatively more of the lighter isotope (H_2) than does the residual water. By repeated electrolysis in stages, heavy water of a high degree of purity can be obtained.

1.85 Each of the three foregoing procedures has certain advantages under appropriate conditions. Hence, in the production of heavy water in quantity, ordinary water is first partially enriched in deuterium by the isotopic exchange process with hydrogen sulfide. The deuterium is further concentrated by fractional distillation of the enriched water under reduced pressure, and then it is brought up to 99.75 percent purity by electrolysis. Deuterium gas can be released from heavy water by any of the familiar chemical processes used to prepare hydrogen gas. It can then be very simply converted into any compound that may be required, e.g., uranium deuteride (UD_3), lithium deuteride (LiD), etc., for weapons applications.

1.86 The third isotope of hydrogen, i.e., tritium, is a radioactive beta emitter, with a half-life of 12.33 years. It is found in natural waters to an insignificant extent only and the cost of extraction would be prohibitive. Consequently, tritium is produced by nuclear reactions resulting from the exposure of lithium (as a suitable compound) to neutrons in a reactor. The less abundant lithium-6 isotope, present to the extent of 7 atomic percent in natural lithium, readily captures slow neutrons and undergoes the (n,α) reaction

$$^{6}_{3}\mathrm{Li} + {}^{1}_{0}n \rightarrow {}^{4}_{2}\mathrm{He} + {}^{3}_{1}\mathrm{H}\ (\text{or T})$$

with the formation of tritium. The more common isotope, lithium-7, reacts with fast neutrons to some extent and this process also leads to the production of tritium; thus,

$$^{7}_{3}\mathrm{Li} + {}^{1}_{0}n \rightarrow {}^{4}_{2}\mathrm{He} + {}^{3}_{1}\mathrm{H}\ (\text{or T}) + {}^{1}_{0}n.$$

1.87 After irradiation by neutrons for a length of time, the lithium compound is removed from the reactor and the gases, consisting mainly of tritium and helium, with other hydrogen isotopes as impurities, are separated from the residual solid. Purification is achieved by a gaseous diffusion process. Compounds of tritium can be prepared from the gas by reactions similar to those employed for deuterium and ordinary (light) hydrogen.

Enrichment of Lithium

1.88 For the production of tritium, described above, it is not necessary to separate the lithium-6 from the more abundant lithium-7. Natural lithium is consequently used for this purpose. For certain applications, e.g., in some thermonuclear weapons, however, it is required that the lithium, which is employed as a hydride,* be enriched in the lighter isotope. Such material, with a lithium-6 enrichment of up to 90 percent, is produced by the counter current flow of

*Used generically, the term hydride refers to a binary compound containing any of the isotopes of hydrogen.

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lithium amalgam, Li(Hg), and an aqueous solution of lithium hydroxide, Li^+OH^-, in a cascade of packed columns. The amalgam is obtained by the electrolysis of lithium hydroxide solution using a mercury cathode.

1.89 The lighter isotope is concentrated in the amalgam by the exchange reaction

$$^7Li(Hg) + {}^6Li^+ \rightleftharpoons {}^7Li^+ + {}^6Li(Hg),$$

and is recovered by decomposing the amalgam with pure water in the presence of a graphite catalyst, i.e.,

$$^6Li(Hg) + H_2O = {}^6LiOH + Hg + \tfrac{1}{2}H_2.$$

A portion of the resulting (enriched) lithium hydroxide is drawn off as the product and the remainder is refluxed to the cascade. The recovered mercury is returned to the amalgam maker at the head of the cascade.

1.90 The hydroxide enriched in lithium-6 is neutralized with hydrochloric acid; the resulting aqueous solution of lithium chloride is concentrated by evaporation and the salt is allowed to crystallize. Lithium metal is then obtained by electrolysis of the molten lithium chloride. For the production of various lithium hydrides enriched in ^6Li, the metal is reacted at a suitable temperature with the appropriate isotope of hydrogen under pressure.

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Chapter 2

THE FISSION PROCESS IN WEAPONS

INCREASE OF NEUTRON POPULATION

The Multiplication Rate: Alpha

2.01 No matter how it originates, an explosion is associated with the very rapid liberation of a large amount of energy within a restricted space. If the energy is to be produced by fission, then an essential condition for explosion is a very high neutron density, since the rate of fission, and hence the rate of energy release, is proportional to the number of free neutrons per unit volume. It is of interest, therefore, to examine the factors which lead to a high neutron density, since these will form a basis for fission weapon design.

2.02 In accordance with the definition of the effective multiplication factor, k, given in § 1.19, it follows that for every n neutrons present at the beginning of a generation there will be nk neutrons at the beginning of the next generation, so that the gain of neutrons is $n(k-1)$ per generation. The rate of gain, dn/dt, may then be obtained upon dividing the actual gain by the average time, τ, between successive fission generations; hence,

$$\frac{dn}{dt} = \frac{n(k-1)}{\tau}. \tag{2.1}$$

Equation (2.1) will be strictly correct only if delayed neutrons play no part in maintaining the fission chain. As already stated (§ 1.13), this condition is applicable, to a good approximation, to nuclear fission weapons.

2.03 The quantity $k-1$, which is the excess number of available neutrons per fission, may be represented by x, i.e.,

$$x \equiv k-1, \tag{2.2}$$

and then equation (2.1) becomes

$$\frac{dn}{dt} = \frac{x}{\tau} n. \tag{2.3}$$

The time rate of increase (or decrease) in neutron population can be expressed in the general form

$$\frac{dn}{dt} = \alpha n, \tag{2.4}$$

where α is the specific rate constant for the process which is responsible for the change in the number of neutrons. In nuclear weapons work this constant is called the multiplication rate or merely "alpha." Comparison of equations (2.3) and (2.4) shows that for a fission chain reaction

$$\alpha = \frac{x}{\tau}. \tag{2.5}$$

Since τ is the time per fission generation and x is a number (per fission), the units of α are generations per unit time or generations/time.

2.04 The foregoing results are applicable regardless of whether x, and hence α, is positive, zero, or negative. For a subcritical system, $k < 1$ (§ 1.20), i.e., $k-1$ is negative; in these circumstances x is negative and so also is α. It follows from equation (2.4) that dn/dt is then negative and the number of neutrons in the system will decrease with time. Consequently, in agreement with previous conclusions, the fission chain in a subcritical system will eventually die out because of the steady decrease in the neutron population. When the system is just critical, $k = 1$, and x and α are both zero; the number of neutrons will thus remain constant. Finally, for a supercritical system, $k > 1$, and x and α are positive; there will then be a steady increase in the neutron population. Since dn/dt is proportional to n, by equation (2.4), it is evident that in a supercritical system, the number of neutrons will grow at increasingly faster rates as n increases.

2.05 Another aspect of the significance of α becomes apparent when equation (2.4) is written in the form

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$$\frac{dn}{n} = \alpha\, dt.$$

If α is assumed to remain constant, an acceptable assumption for a simple fission device somewhat before explosion, this expression can be readily integrated between the time limits of zero, when the number of neutrons present is n_0, and t, when the number is n. The result is

$$n = n_0 e^{\alpha t}, \qquad (2.6)$$

where, as usual, e is the base of natural logarithms. This expression, like those given above, is applicable regardless of whether α is positive, zero, or negative. If α is known, equation (2.6) can be used to calculate the neutron population at any time t relative to the value at any arbitrary zero time. It can also be seen from equation (2.6) that $1/\alpha$ is the time period during which the number of neutrons changes by a factor e; consequently, $1/\alpha$ is often referred to as the e-folding time, i.e., the time in which there is an e-fold change in the neutron population.*

Measurement of Alpha

2.06 The value of α is a highly important quantity in weapons design, as will shortly be apparent. It is generally obtained from a computer calculation based on the neutronic and hydrodynamic characteristics of the system, but there are uncertainties involved and experimental measurements are desirable. In weapons tests, the alpha measurement is one of the most important diagnostic requirements. Calculations are then normalized to agree with the observed values for each type of implosion system.

2.07 The determination of α involves the measurement of the time variation of the neutron population in the exploding system during a period of a microsecond or less. It follows from equation (2.6) that if $\log n$ is plotted against time, the slope of the curve will give α. The quantity measured is not n, the actual neutron population, but some parameter which is proportional to it. Because the number of neutrons emitted per fission varies, the relationship between the total number of neutrons and the total fissions is statistical rather than exact. More important is the fact that, since some neutrons are lost by nonfission captures and by escape, not all the fission neutrons are available for causing fissions in the next generation. However, at any given instant, the fission rate is proportional to n at that instant, and so the time variation of any quantity proportional to the fission rate can be used to determine α. A convenient quantity of this kind which lends itself to ready measurement is the gamma-ray flux emitted from the exploding weapon.

2.08 One method for determining α is to place a number of gamma-ray scintillation detectors fairly close to the device to be exploded. These detectors are connected by coaxial cables to oscilloscopes located at some distance. When the explosion occurs the detectors will respond to the gamma-ray flux in their vicinity and will send appropriate signals to the oscilloscopes before being destroyed by the explosion. Instead of the gamma-ray flux, the neutrons escaping from the system have sometimes been used to determine α. The rate of escape may be regarded as being proportional to the neutron population in the weapon undergoing fission.

2.09 During the design phase of a weapon, α is computed theoretically and laboratory experiments, which do not involve nuclear explosions, are used to provide normalization points for the calculations. Since a supercritical (or even a critical) mass cannot be handled safely under ordinary conditions, experimental measurements of α are made with a mass that is slightly subcritical. In the Rossi method, a single neutron is introduced at intervals into a slightly subcritical system. One (effective) neutron starts a fission chain which soon dies out; then another neutron starts a second chain which dies out, and so on for the duration of the experiment. The counters are thus exposed over an appreciable period to neutrons from a large number of chains one at a time, and so the method is statistical in character. The neutron counting is carried out by means of a multichannel time-delay circuit. The first channel is activated by entry of a neutron; then, after a pre-determined interval, a second channel is activated for a short time; after a further interval, a third channel is activated, and so on for intervals ranging from 0.25 μsec to a total of a few milliseconds. From the accumulated counts for the various channels, the time rate of decay of the prompt neutrons after fission can be determined and α calculated from equation (2.6).

2.10 The values of α obtained as described above apply to the particular subcritical system used. In order to estimate what α would be in a supercritical

*It will be shown in §2.16 that x is about 1, so that $\alpha \approx 1/\tau$ by equation (2.5); hence, $1/\alpha$ is approximately equal to the generation time. The neutron population thus changes by about a factor of e (= 2.72) in each generation.

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(weapon) assembly of the same materials, an extrapolation procedure can be employed. By means of a number of measurements with different assemblies, α can be determined as a function of the number of (prompt) crits present. The values could then be extrapolated to give α for the number of crits expected at the time of initiation of the weapon. Such a procedure is highly uncertain since it involves extrapolation from a series of assemblies which are slightly subcritical to one which is highly supercritical. As previously noted, detailed machine calculations, normalized to experimental results, are currently used to estimate α values.

Conditions for Nuclear Explosion

2.11 It was pointed out in § 2.01 that the essential condition for a nuclear fission explosion is a very high density of free neutrons. Equation (2.6) shows that if a large density n is to be attained within a short time, α must be large. In general, the magnitude of α determines the efficiency of a nuclear explosion, and it is of interest to consider how α may be made as large as possible.

2.12 According to equation (1.4), k is equal to $\nu-l$, where ν is the average number of neutrons produced in each act of fission and l is the average number lost per fission by escape and in other ways. Upon utilizing this result, together with equations (2.2) and (2.5), it follows that

$$\alpha = \frac{x}{\tau} = \frac{\nu-l-1}{\tau}. \qquad (2.7)$$

In order to increase α it is consequently necessary that $\nu-l-1$ be large and τ be small. The value of ν is a specific property of the fissile material for fission by neutrons of a given energy. Since ν increases with neutron energy, it would appear to be advantageous from this standpoint if most of the fissions in a weapon were caused by fast neutrons. The relative neutron loss, l, can be decreased, e.g., by assembly or compression or by using a neutron tamper. If the volume increases, the loss of neutrons per fission increases and α will decrease accordingly.

2.13 A highly significant contribution to the magnitude of α is made by the fission generation time, τ. This is approximately equal to λ, the fission mean free path of the neutrons in the core material, divided by the (average) speed, v, of the neutrons causing fission, i.e.,

$$\tau \approx \frac{\lambda}{v}, \qquad (2.8)$$

so that in a fission weapon it is desirable that the ratio λ/v be as small as possible. It should be noted that the fission mean free path in equation (2.8) is not the same as the total mean free path for all interactions used in § 1.43. The λ employed here is the average distance a neutron travels before it is captured in a fission reaction.

2.14 The fission mean free path is equal to $1/N\sigma_f$, where N is the number of fissile nuclei per cm^3 and σ_f is the fission cross section.* Hence, from equation (2.8),

$$\tau \approx \frac{1}{N\sigma_f v}, \qquad (2.9)$$

and the generation time is inversely proportional to the product $\sigma_f v$. The value of σ_f decreases as v increases but the product is $\sim 2 \times 10^9$ (in 10^{-24} cm^3/sec units) for fast neutrons of 1-MeV energy compared with 10^8 for slow neutrons. Hence, the fission generation time is appreciably shorter for fast than for slow neutrons.

2.15 From the information already given, it is possible to make rough, order-of-magnitude estimates of τ and α. For uncompressed uranium-235 or plutonium-239, the number, N, of nuclei per cm^3 is approximately 0.5×10^{23} and, as stated above, $\sigma_f v$ for fast-neutron fission is $2 \times 10^9 \times 10^{-24} = 2 \times 10^{-15}$ cm^3/sec. Hence, from equation (2.9),

$$\tau \approx 1/(0.5 \times 10^{23})(2 \times 10^{-15}) \approx 10^{-8} \text{ sec.}$$

The generation time for fast neutrons in a fission weapon is thus roughly 10^{-8} sec, i.e., 1 shake, or 0.01 microsecond, i.e., 0.01 μsec.

2.16 As seen from Table 1.1, ν is about 2.5 to 3, and the loss, l, of neutrons per fission may be taken to be 0.5 to 1. Hence, by equation (2.2), the value of x is close to unity for a highly supercritical system. It follows, therefore, from equation (2.7) that

$$\alpha \approx \frac{1}{\tau} \approx 10^8 \text{ gen/sec (or } 10^8 \text{ gen sec}^{-1}\text{).}$$

*For the present purpose it is sufficient to regard the cross section as the effective area in sq cm of a nucleus for a particular reaction (or reactions). Cross sections vary with the neutron energy and the fission cross sections for uranium-235 and plutonium-239 have been measured over a large energy range.

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Thus, for fast-neutron fission α is approximately 10^8 gen/sec.

2.17 Values of α are commonly expressed either in generations per shake, i.e., gen/shake, or per microsecond, i.e., gen/μsec. The rough calculations made above indicate that, in a weapon, α is of the order of 1 generation per shake or 100 generations per μsec. Experimental measurements, both in the laboratory and at weapons tests, show that this is indeed the case.

2.18 It is evident that in order to achieve an efficient nuclear explosion, fission should be brought about by fast neutrons, as far as possible. For such neutrons, the factors ν and τ, and to some extent l, favor a high value of α and, hence, a rapid increase in the neutron population. It would appear desirable, therefore, to keep elements of low mass number, which slow down neutrons more effectively than heavier ones, out of the core, in particular, as well as the reflector of a fission weapon. At one time, special precautions were taken to do so, but in recent years the element beryllium, mass number 9, has been widely used as a reflector material in small weapons because of its satisfactory neutronic properties (see Table 1.2) and low mass.

2.19 According to equation (2.9), the fission generation time for neutrons of a given energy (or velocity) is inversely proportional to the number, N, of fissile nuclei per cm^3. It follows, therefore, that τ is inversely proportional to η, the core compression ratio; thus

$$\tau \propto \frac{1}{\eta}. \qquad (2.10)$$

Consequently, the generation time can be decreased, and the value of α increased proportionately, by compression of the core material.

2.20 In addition to the effect on τ, compression also causes a marked decrease in l for the reason given in § 1.40. This also contributes to an increase in α, as follows from equation (2.7). It is seen, therefore, that compression of the core will cause an increase in α because of the decrease in both τ and l.

Explosion Time

2.21 Suppose that a slightly subcritical mass of fissile material is compressed, as in an implosion device. The system will pass through a critical configuration, referred to as "first critical," and then become increasingly supercritical. After reaching a stage of optimum (or maximum) supercriticality, corresponding to optimum assembly or maximum compression, the system would subsequently become less and less supercritical. If a fission chain is initiated by the introduction of neutrons, the variation of α with time would be qualitatively as indicated in Fig. 2.1.

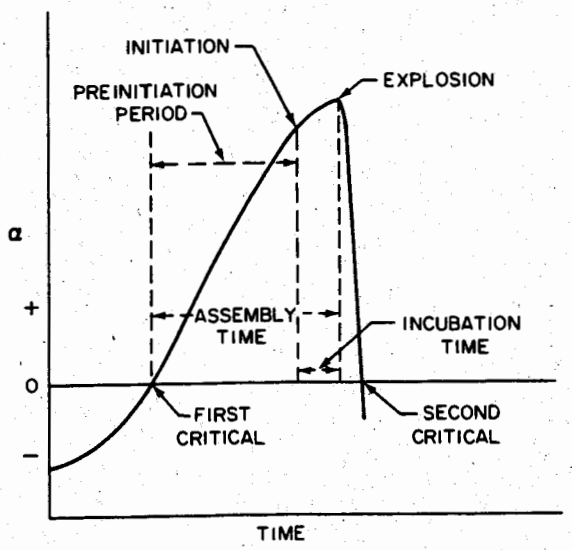


Figure 2.1

2.22 If a divergent chain reaction, leading to an explosion, is to be established in the system, at least one neutron must be present while the system is supercritical, i.e., after first critical. For maximum efficiency, the explosion should occur as close as possible to maximum supercriticality and the neutrons should be introduced at an appropriate earlier time. For the present general discussion, it will be assumed that the fission chain is initiated before optimum supercriticality, as is the usual situation for implosion systems.

2.23 Once the fission chain has been started, energy release will commence. The motion of the fissile material in the assembly process will not be affected significantly, however, until the energy generated by fission produces appreciable mechanical forces. After a certain time, the increase of temperature accompanying the release of the fission energy will generate expansion pressures high enough to stop the motion of the assembly, and subsequently disassembly will begin. The point at which assembly ceases and disassembly commences is known as the "explosion time." The interval between initiation of the fission chain by a neutron and explosion time is referred to as the

"incubation time" (Fig. 2.1). The time between first critical and explosion (or maximum supercriticality) is here called the "assembly time."*

2.24 Because of the rapid increase in the neutron population during the propagation of the fission chain reaction, the fission energy is released at a very high rate. The heat generated causes the temperature to increase and the fissile material expands (or disassembles) rapidly. Soon the volume becomes so large that the system becomes subcritical and the divergent chain reaction ceases. The point at which the material passes through the critical stage during expansion is called "second critical" (§ 2.59).

2.25 The number of fission generations corresponding to the explosion time for a spherical (imploded) core can be calculated in a semiquantitative way in the following manner.† If the reasonable assumption is made that the pressure in the assembly has a parabolic distribution, then the pressure P at a distance r from the center of the core of radius R is

$$P = P_0\left(1 - \frac{r^2}{R^2}\right), \tag{2.11}$$

where P_0 is the pressure at the center. If $\bar{P}$ is the average pressure in the core then, as shown in the appendix to this chapter,

$$\bar{P} = \frac{1}{5}\rho R a, \tag{2.12}$$

where ρ is the density of the core material and a is the acceleration at its surface.

2.26 If the change in velocity at the surface of the core at a time t after initiation of the chain reaction is represented by Δv, then

$$\Delta v = \int_0^t a\,dt. \tag{2.13}$$

Furthermore, with an exponentially increasing neutron population, as indicated by equation (2.6), the acceleration, as well as the energy density and the pressure, will vary as $e^{\alpha t}$; hence,

$$a = Ae^{\alpha t},$$

where A is a constant. If this result is substituted into equation (2.13), it is seen that

$$\Delta v = \frac{a}{\alpha}. \tag{2.14}$$

2.27 Suppose the unperturbed velocity of the core surface during assembly, i.e., before it is affected by the fission energy, is v_0; then the assembly motion will be halted when

$$\Delta v = v_0, \tag{2.15}$$

and this corresponds to explosion time. Consequently, from equations (2.14) and (2.15), at explosion time

$$a = v_0\alpha,$$

and from equation (2.12)

$$\bar{P} = \frac{1}{5}\rho R v_0 \alpha. \tag{2.16}$$

This is the average pressure in the core at explosion time.

2.28 The application of equation (2.16) may be illustrated by considering the hypothetical case of a core with a density, ρ, of 20 g/cm^3, and a radius, R, of 5 cm. The unperturbed rate of assembly, v_0, may be [redacted] DOE b(3)
and α is set at 1 gen/shake, i.e., 10^8 gen/sec. If these values are substituted into equation (2.16), it follows that at explosion time

[redacted] DOE b(3)

2.29 At explosion time, the core will be effectively a gas at very high pressure and it may be considered to

*In weapons test, a measured time interval is that between firing the HE system and the first appearance of gamma rays from the explosion; it is called the "HE transit time" or simply the "transit time."

†The purpose of this treatment is merely to provide a general understanding of the core behavior. In weapons design studies, more exact calculations are made with the aid of computers.

‡The unit 1 bar is equivalent to a pressure of 10^6 dynes/cm^2; the megabar, i.e., 10^6 bars, is then 10^{12} dynes/cm^2. The standard atmospheric pressure (760 mm of mercury) is 1.013 bars; thus a pressure of 1 atm is approximately 1 bar.

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have been compressed adiabatically. The energy, E, of the core will then be given by

$$E = \frac{PV}{\gamma - 1}. \qquad (2.17)$$

For an ideal gas, γ is $\frac{5}{3}$, but for the core it is probably nearer to $\frac{3}{2}$. Hence, using the value of $\bar{P}$ derived above, it is found that at explosion time the energy per unit volume is

DOE b(3) $\bar{E}_v =$ [redacted]

provided the loss of energy from the system prior to this time is not significant.

2.30 Since the density of the core has been taken to be 20 g/cm^3, the average energy per gram, $\bar{E}_g$, at explosion time in the hypothetical case under consideration is

DOE b(3) $\bar{E}_g =$ [redacted]

DOE b(3) [redacted]

2.31 The radius of the core is 5 cm and hence the volume, V, is $\frac{4}{3}\pi(5)^3 = 524$ cm^3. The total energy, E, released by explosion time, is, therefore,

DOE b(3). $E = \bar{E}_v V =$ [redacted]

which is equivalent (§ 1.15) to

DOE b(3) [redacted] ons TNT.

Consequently, an energy [redacted] ons of DOE b(3) TNT is released by explosion time in the case under consideration.

2.32 The amount of fission energy contributing to the explosion is equivalent to 7×10^{-24} kiloton (or 7×10^{-21} ton) per fission (§ 1.15). Hence, at explosion time the number of fissions that have occurred is

DOE b(3) Number of fissions = [redacted]

2.33 It was seen in § 2.16 that x is approximately equal to unity in a weapon and then α is roughly equivalent to $1/\tau$. Consequently, equation (2.6) may be written as

$$n \approx n_0 e^{t/\tau} = n_0 e^g,$$

where t/τ, represented by g, is the number of generations in which the neutron population increases from n_0 to n. If it is postulated that the fission chain is initiated by a single neutron, the number of neutrons present after g generations is

$$n \approx e^g.$$

As an approximation, it may be assumed that the number of fissions after g generations is equal to the neutron population, n, at that time. Hence, it follows that in the hypothetical example used above explosion time occurs [redacted] DOE b(3)

2.34 It will be evident from the foregoing treatment that the explosion time depends on such quantities as ρ, R, v_0, and α, and hence it will vary with the design of the fission weapon [redacted] DOE b(3)

2.35 In this derivation of explosion time it has been assumed that the fission chain is initiated by one neutron. The results would not be affected significantly if a few neutrons were present at initiation time. In some types of initiators, however, many neutrons are supplied to start fission chains. The number of generations at explosion time will then be less than obtained above [redacted] DOE b(3)

2.36 Another point that should be mentioned about these calculations is the assumption that the

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total number of fissions which have occurred by a particular time is equal to the neutron population at that time. This assumption represents a simplification of the actual situation. A more precise treatment, however, leads to results in agreement with those obtained above.

Rate of Energy Release

2.37 Since the explosion energy released per fission is equivalent to 7×10^{-21} ton of TNT and the total number of fissions at g generations may be set equal to e^g, assuming initiation by a single neutron, it follows that

$$\text{Energy released by } g \text{ generations} \approx 7 \times 10^{-21}\, e^g$$
$$= 7 \times 10^{-21} \times 10^{g/2.3} \text{ tons TNT.}$$

The energy releases after various numbers of generations have been calculated from this expression; some of these are quoted in Table 2.1.

Table 2.1 TOTAL ENERGY RELEASE

No. of generations	Energy release (TNT equivalent)
[redacted]	

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2.38 [redacted] It is evident from the results in Table 2.1 that nearly all the energy is released in the next 7 (or so) generations. The reason is, of course, that the energy increases by a factor of $e = 2.72$ in each generation or, $e^7 \approx 10^3$ in 7 generations.

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2.39 It is true, in general, that only a small proportion, usually something like 0.1 percent (1 part in 10^3) of the energy of a fission weapon is produced by explosion time; the remaining 99.9 percent is released during the next few generations. It is thus accepted that before explosion time, at [redacted] generations after initiation, the energy release is too small to have any appreciable effect on the motion of the assembly. Within this period, therefore, the core volume may be assumed to remain essentially constant.

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2.40 In a simple device with a short incubation period the core volume is more or less constant between initiation and explosion time; hence, α in a pure fission (but not boosted) device is also roughly constant. After explosion time, however, when the system expands, α decreases and the generation time increases. As a rough approximation, however, the generation time may be taken to be 1 shake. Hence, it is during a period of about 7 shakes, i.e., 0.07 μsec, that most of the energy of a fission device is produced. The release of a large amount of energy in such a very short interval of time, in a restricted volume, results in the attainment of very high temperatures—several tens of million degrees. Large pressures consequently develop in the core and rapid expansion, i.e., an explosion, occurs.

2.41 When the expansion is such that α has fallen to zero and the system passes through second critical, the self-sustaining fission chain will cease, although substantial amounts of fissile material may still be present. To attain a high efficiency, i.e., to consume as much as possible of the fissile species, expansion of the core should be delayed. This important function in pure fission weapons was filled by the inertial tamper. In boosted devices, however, the introduction of neutrons from an extraneous (D-T) source results in a considerable increase in the fission rate before the system expands significantly. The inertial tamper then appears to be less important than in an unboosted system.

EFFICIENCY OF FISSION WEAPONS

Definition of Efficiency

2.42 The efficiency, ϕ, of any weapon may be defined as the ratio of the energy actually developed when it explodes, i.e., the energy yield, to the total energy available; thus,

$$\phi = \frac{\text{Energy yield}}{\text{Energy available}}. \qquad (2.18)$$

In other words, the efficiency is the fraction of the total energy available which is actually released in the explosion. In the case of a fission weapon, this is equal to the ratio of the quantity of fissile material which actually suffers fission to the total amount present in the weapon. The efficiency of a weapon is generally expressed as a percentage, and so it is equal to ϕ, as defined by equation (2.18), multiplied by 100. There are several factors which determine the efficiency and some of these will be discussed below.

2.43 It is of interest to mention, in passing, that the efficiency of the earliest implosion weapons was [redacted] the gun-type systems (§ 1.56). This accounts for the fact that devices of the latter type have occupied a secondary place in the development of fission weapons, except for special purposes.

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Calculation of Efficiency: Computer Methods

2.44 At the present time, the efficiency or, more correctly, the energy yield of a weapon is determined by computer calculations based on codes which have been developed to represent the behavior of the fission chain system. The calculations usually start at or immediately before explosion time, when significant mechanical effects may be assumed to begin. From initiation up to this time, the material is essentially stationary or is still being compressed and only a small proportion of the total energy has been liberated. The treatment takes into account the neutronic behavior, the hydrodynamics, and heat flow; the motion of a series of concentric shells (or "mass points") is followed until the rate of energy release by fission has fallen almost to zero. The total yield includes the energy released after the system has expanded and become subcritical. Although self-sustaining chain propagation is no longer possible, convergent-chain interaction of the many neutrons and fissile nuclei still present will result in considerable energy production. This may amount to some 30 percent or more of the total yield.

The Bethe–Feynman Formula

2.45 Prior to the development of computing machine procedures, and before data were available from test explosions for comparison and normalization purposes, fission weapon efficiencies were estimated by the method of Bethe and Feynman. The basic formula is admittedly approximate, since it involves several simplifying assumptions. However, its derivation is useful in the respect that it provides a model of the explosion of a fission weapon and indicates, qualitatively at least, some of the factors which affect the efficiency of the explosion. The treatment given below is applicable to pure fission systems and not after boosting occurs.

2.46 As a result of the energy liberated in fission, very large pressures (10–1000 megabars) are developed in the core, and the core-tamper interface consequently receives a large outward acceleration. This causes highly compressed tamper material to pile up just ahead of the expanding interface, in an effect referred to as the "snowplow" phenomenon, because of the similarity to the piling up of snow in front of a snowplow. The inertia of the compressed tamper delays expansion of the core, so that a considerable pressure gradient builds up from the center of the core to its outer surface.

2.47 Furthermore, because of the delayed expansion, it may be supposed that the volume of the compressed (supercritical) core remains essentially constant during the [redacted] or so generations following initiation of the fission chain, i.e., up to explosion time. After this interval, almost the whole of the energy is released within an extremely short period, during which time the supercritical core expands rapidly until it becomes subcritical. Although there is an appreciable release of energy even while the system is subcritical, as mentioned in § 2.44, it will be postulated that energy production ceases when the dimensions are just subcritical. It will be assumed, further, that no energy escapes during the short period of expansion from maximum supercriticality to the point where the system becomes subcritical.

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2.48 Let R be the radius of a spherical core at the point of maximum supercriticality; then, in accordance with the postulate made above, this will remain unchanged until explosion time. Subsequently, the energy density of the system becomes so large that mechanical effects begin and the core starts to expand. Suppose that when the core has expanded by a fraction δ, so that the radius is $R(1 + \delta)$, the system is just critical (Fig. 2.2); beyond this point it will be subcritical. The self-sustaining fission chain will then end and, in accordance with the approximation postulated above, there will be no further release of energy.

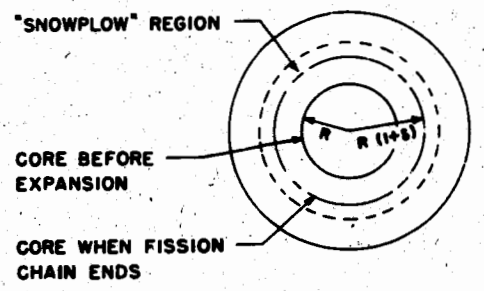


Figure 2.2

2.49 Consider a thin shell of material in the core, of volume dV and thickness dR; the cross sectional area of the shell is then dV/dR. If dP is the pressure difference on the two sides of this shell, caused by the liberated fission energy, the net outward force, dF, to

which the shell is subjected, i.e., pressure × area, is then

$$dF = dP\frac{dV}{dR} = \frac{dP}{dR}dV, \tag{2.19}$$

where dP/dR is the pressure gradient in the given shell. As a reasonable approximation, it may be supposed that the pressure gradient is essentially constant across the core radius, so that

$$\frac{dP}{dR} \approx \frac{P}{R}, \tag{2.20}$$

where P is the total difference in pressure from the center of the core to the outer surface before expansion occurs. Hence, from equations (2.19) and (2.20),

$$dF \approx \frac{P}{R}dV. \tag{2.21}$$

2.50 The time required for the core to expand from radius R to $R(1+\delta)$, i.e., a distance of $R\delta$, is about 7 generations, as seen in § 2.38. However, as a rough approximation, this may be taken as $1/\alpha$, where α is the multiplication rate just prior to explosion time. The mean outward acceleration of the core material, and of the shell dV, may consequently be expressed as $R\delta\alpha^2$. The mass of the shell is ρdV, where ρ is the core density; hence, by Newton's second law of motion, i.e., force = mass × acceleration, the force dF acting on the shell is given by

$$dF \approx \rho dV \times R\delta\alpha^2.$$

Upon comparing this result with equation (2.21), it is seen that

$$P \approx \rho R^2\alpha^2\delta. \tag{2.22}$$

2.51 As in the calculation of the explosion time, the total energy of the core, assuming there is negligible loss during the initial expansion, is expressed by equation (2.17), namely,

$$E = \frac{PV}{\gamma - 1}, \tag{2.23}$$

where γ is the ratio of the specific heats of the gas. Using equation (2.22) for P and writing M/ρ for the volume of the core, M being the mass, equation (2.23) becomes

$$E \approx \frac{MR^2\alpha^2\delta}{\gamma - 1}. \tag{2.24}$$

2.52 If ϵ is the energy released in the complete fission of unit mass of core material, then the total energy available in the core is $M\epsilon$, and the efficiency, according to equation (2.18), is $E/M\epsilon$, where E is given by equation (2.24); consequently,

$$\phi = \frac{E}{M\epsilon} \approx \frac{R^2\alpha^2\delta}{(\gamma - 1)\epsilon}. \tag{2.25}$$

It should be pointed out that in the foregoing derivation no allowance has been made for depletion of the core material as fission proceeds. For low efficiencies, to which most of the other approximations made are applicable, the depletion is not significant and can be neglected. Moreover, no allowance has been made for the inertial effect of the tamper on the efficiency. For the present purpose, which is to obtain a qualitative guide to some of the factors determining the efficiency, this can also be ignored. Hence, replacing the quantity $1/(\gamma - 1)\epsilon$ by a constant, K, equation (2.25) can be written as

$$\phi \approx KR^2\alpha^2\delta, \tag{2.26}$$

which is a version of the Bethe–Feynman formula that was developed for slightly supercritical systems. The efficiency of a fission weapon is seen to depend on the factors R, α, and δ.

2.53 Since the efficiency of a fission weapon may be expected to increase as R^2 (at constant density), it would be advantageous for the core to be large at the time of the initiation of the fission chain. One way in which this can be achieved in practice, e.g., in a gun-type weapon, is to bring together subcritical masses which are designed to contain a large total mass of fissile material. Thus, for a given compression or, especially, for no compression, the efficiency would be expected to be greater the larger the mass of the assembled core.

2.54 In general, the most important factor in determining the efficiency of a fission weapon is α, and the latter increases in proportion to the compression (§ 2.19). The efficiency, according to equation (2.26), will thus be related, approximately at least, to η^2 (or to $\eta^{1.7}$ if the effect of tamper compression is included (§ 1.47)). In addition, although of lesser significance, the effect of compression on δ must be taken into account; the more highly compressed the core material

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at the time of initiation (or at explosion time), the farther will be the distance the core surface must travel during the expansion phase before the supercritical system becomes subcritical. Increased compression should thus result in a marked gain in the efficiency of a fission weapon. It is this fact which is largely responsible for the much higher efficiencies of implosion systems than of gun-type devices.

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2.55 The effect of increasing compression in a simple (unboosted) implosion system is indicated by the data in Table 2.2 which are based partly on experimental observations and partly on calculation.

Table 2.2 EFFECT OF COMPRESSION ON EFFICIENCY

Average compression		Efficiency
Core	Tamper	(percent)

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The attainment of high compression was an important objective in pure fission weapon design. In the earliest (solid-core) devices the improvement in efficiency was the main purpose. In more recent (hollow-core boosted) weapons, however, the principal objective is to make possible the design of compact systems in which both the high explosive (§ 1.42) and the fissile material have low masses. The number of crits at maximum compression is not large, so that α is relatively small before boosting. The initial efficiency of the fission chain is, therefore, also small but the total yield is greatly increased by the boosting.

INITIATION TIME AND PREINITIATION

Unboosted Implosion Weapons

2.56 It was indicated in Chapter 1 that preinitiation of a fission weapon, i.e., initiation of a chain reaction before the optimum time, could lead to a decrease in efficiency. The reason for this will be clear from the results derived in the preceding section. According to equation (2.26), the efficiency is proportional to α^2 and hence initiation at a time that will lead to explosion before α has attained its optimum value (see Fig. 2.3), i.e., preinitiation, would inevitably result in a loss of efficiency in a simple (unboosted) fission device.

2.57

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Fortuitously, major advances in the design of weapons with improved characteristics led at the same time to a decrease in preinitiation probability. Such advances included the use of composite cores containing both plutonium and oralloy, with smaller amounts of plutonium than in all-plutonium cores, and the development of small weapons with hollow cores.

2.58 The problems of preinitiation and its avoidance are conveniently considered in relation to the assembly and incubation times defined in § 2.23. In an unboosted, solid-core device, the system is initially subcritical and upon assembly it passes promptly through first ciritical and then becomes supercritical, as already described. The value of α is negative before first critical, it is zero at first critical, and becomes increasingly positive during assembly (Fig. 2.3). Prior to initiation, of course, there is no neutron multiplication and hence no actual α, but the curve in Fig. 2.3 shows the potential α at various times during assembly.

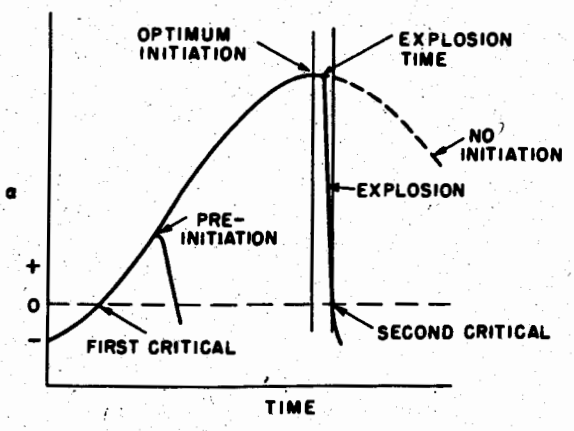


Figure 2.3

2.59 Just before optimum assembly, where α is approaching its maximum value, neutrons are injected into the highly supercritical system. The divergent

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fission chain is initiated and energy is released. Between initiation time and explosion time the volume is more or less constant and so also is α (§ 2.40). Rapid expansion, however, results in loss of neutrons at an increasing rate and causes the core to become less and less supercritical; hence α decreases rapidly after explosion time. When second critical is reached, both the neutron population and the rate of fission have their maximum values. Beyond second critical a self-sustaining chain reaction is no longer possible; nevertheless, considerable amounts of energy are produced by convergent chains in the subcritical system.

2.60 It is seen from Fig. 2.3 that for the particular type of simple fission weapon under consideration, the assembly time, i.e., between first critical and explosion, is long compared with the incubation time, i.e., between initiation and explosion time.

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Because of the longer assembly times, preinitiation is more probable in gun-type than in implosion systems. Some aspects of preinitiation in weapons of the former type are discussed later (§ 2.73).

2.61

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2.71 [redacted]

DOE 6(3)

Use of Dirty Plutonium in Implosion Weapons

2.72 [redacted]

DOE 6(3)

Gun-Type Weapons

2.73 In a gun-type weapon, the lack of compression makes it desirable for initiation to take place at or close to the time when assembly [redacted]

DOE 6(3)

[redacted]

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Consequently, although plutonium-239 with an appreciable proportion of plutonium-240 could be used in implosion systems, even of the solid-core, unboosted type, it is unsuitable for use in conventional gun-assembly devices, as the calculations given below will show.

2.74 Apart from the possible presence of a "flood" of neutrons, e.g., as the result of the explosion of another nuclear weapon in the vicinity of a given weapon, the chief sources of background neutrons, which could cause preinitiation in a gun-assembly weapon, are spontaneous fission and (α,n) reactions with light elements. In uranium-235 (oralloy) the rate of spontaneous fission is relatively small, as will be seen shortly, but (α,n) reactions with light-element impurities could produce an appreciable neutron background. [redacted]

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2.75 Let P_1 be the probability that a background neutron will be available in the fissile material during the period that it is supercritical, i.e., in the preinitiation period, and let P_2 be the probability that this neutron will be able to start a fission chain. The preinitiation probability, P, is then given by

$$P = 1 - e^{P_1 P_2}$$

$$\approx P_1 P_2, \qquad (2.27)$$

the approximate form being applicable when $P_1 P_2$ is small, as it is in cases of interest. Actually P_2 is a function of time and both P_1 and P_2 depend, to some extent, on the position of the neutron and on other factors. For the present purpose, however, which is to draw general conclusions only, specific values will be assigned to P_1 and P_2. A background neutron entering a fissile assembly may escape altogether without being absorbed, or it may be captured in a nonfission

[redacted]

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reaction, or it may initiate a fission chain. Although the probabilities of these three processes are by no means equal, it is sufficient to postulate here that P_2 has a constant average value of 0.3 over the preinitiation period. Hence, for the purpose of making rough estimates, equation (2.27) may be written as

$$P \approx 0.3\, P_1. \qquad (2.28)$$

2.76 As a result of spontaneous fission, uranium-235 emits, on the average, about 0.70 neutron per kilogram per sec, whereas uranium-238 produces roughly 15 neutrons/kg-sec. Consequently, the neutron background in ordinary oralloy (93.2 weight percent uranium-235) is approximately 1.6 neutrons/kg-sec.

[redacted]

DOE 6(3)

2.77 According to the numbers quoted above, more than half of the background neutrons in ordinary (93.2 percent) oralloy arise from the uranium-238 present.

[redacted]

DOE 6(3)

2.78 Because of the high preinitiation probability, it is necessary to keep other background neutrons to a minimum in gun-assembly devices. It is for this reason

[redacted]

DOE 6(3)

t is seen, therefore, that a conventional gun-type weapon, based on plutonium with assembly brought about by a propellant explosive, is completely out of the question. It was the realization of this fact, when plutonium became available, that led to the development of implosion systems (§1.39), together with the expectation that the compression achieved by implosion would lead to greater efficiency.

2.80

[redacted]

DOE 6(3)

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APPENDIX

A2.01 The average pressure P in a spherical imploding core of radius R is defined by

$$\bar{P}V = \bar{P}(\tfrac{4}{3}\pi R^3) = \int_0^R P\,(4\pi r^2)dr, \qquad (2.29)$$

where P is the pressure at the distance r from the center; hence,

$$\bar{P} = \frac{3}{R^3}\int_0^R Pr^2\,dr.$$

It follows, therefore, from equation (2.11), for a parabolic pressure distribution, that

$$\bar{P} = \frac{3P_0}{R^3}\int_0^R \left(1 - \frac{r^2}{R^2}\right)r^2\,dr. \qquad (2.30)$$

The integral in equation (2.30) may be evaluated as follows:

$$\int_0^R \left(1 - \frac{r^2}{R^2}\right)r^2\,dr = \int_0^R \left(r^2 - \frac{r^4}{R^2}\right)dr$$
$$= \frac{R^3}{3} - \frac{R^5}{5R^2} = \frac{2}{15}R^3.$$

If this result is inserted into equation (2.30), it is seen that

$$\bar{P} = \frac{2}{5}P_0. \qquad (2.31)$$

A2.02 Because of the pressure gradient in the core, the material will be accelerated, and this acceleration, $a(r)$, at the radial distance r, is given by the expression

$$a(r) = -\frac{1}{\rho}\frac{dP}{dr},$$

where ρ is the density of the core material. If P is again expressed by equation (2.11), then

$$a(r) = -\frac{P_0}{\rho}\frac{d\left(1 - \frac{r^2}{R^2}\right)}{dr} = \frac{P_0}{\rho}\frac{2r}{R^2}.$$

Hence, the acceleration, a, at the surface of the core, where $r = R$, is

$$a = \frac{2P_0}{\rho R},$$

so that

$$P_0 = \frac{\rho R a}{2}.$$

Upon inserting this expression into equation (2.31), it follows that

$$\bar{P} = \frac{1}{5}\rho R a,$$

which is equation (2.12).

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D/Strat Tech 13/2/7

27 March 2002

Policy Director : reply from Paul Roper.

ENCLOSURE 18 NUMBER

Policy Director

Copy to:
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IRAQ – NUCLEAR WEAPONS

1. You asked for a second opinion on the issue of IRAQ's nuclear weapons capability and how quickly IRAQ might acquire a deployable nuclear capability. I have reviewed the DIS paper and spoken to DI52 and in short I agree with it as a "best guess" broad based scientific judgement although I will introduce a caveat.

2. It is very important to distinguish between hard intelligence and best scientific judgement. As I understand it the former is a little thin on the ground so we have to look at the latter. Let me start with the key ingredient for a nuclear weapon or device which is a source of fissile material (Plutonium or Highly Enriched Uranium (HEU)). The scientific judgement is clear – without such material you cannot make a nuclear weapon. The domestic source of HEU that IRAQ was trying to establish was destroyed after the Gulf War. It is hard to believe that IRAQ has covertly established a domestic source given the relatively large signatures of the necessary facilities and it would almost certainly take a few years from start up to acquire enough material. If fissile material were acquired from abroad then much time would be saved but I suspect the likelihood of this is low but it's purely an intelligence matter.

3. [redacted]

4. Finally, let us assume that against all the odds IRAQ acquires HEU and a viable [redacted] from a third party. The nuclear component would have to be fabricated and integrated with the explosives system and the firing electronics and incorporated in a bomb case. This will all take some time and the one year "guestimate" is reasonable. However my caveat is that the clock does not necessarily start ticking from the moment of fissile material acquisition. Much of the engineering integration including any conventional explosive trials can be conducted in advance. Indeed it is possible to practice casting fissile material components using simulant material (natural or depleted uranium are ideal surrogates for HEU). If all this has been done ahead of time then it might take only a few weeks to complete assembly once fissile material is obtained. The signatures of some of these precursor activities is quite low but it is on intelligence judgement as to the likelihood of detecting it.

POLICY DIRECTOR
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5. A more advanced design suitable for deployment on a missile would almost certainly involve more development work and explosive trials. I have no feel for timescale but 2-3 years is a good guess. Again most of this work can be done in advance of acquiring the fissile material.

P W ROPER
D Strat Tech
5/26MT 87126MB

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IRAQ'S WEAPONS OF MASS DESTRUCTION

THE ASSESSMENT OF THE BRITISH GOVERNMENT

IRAQ'S WEAPONS OF MASS DESTRUCTION

THE ASSESSMENT OF THE BRITISH GOVERNMENT

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FOREWORD BY THE PRIME MINISTER, THE RIGHT HONOURABLE TONY BLAIR MP

The document published today is based, in large part, on the work of the Joint Intelligence Committee (JIC). The JIC is at the heart of the British intelligence machinery. It is chaired by the Cabinet Office and made up of the heads of the UK's three Intelligence and Security Agencies, the Chief of Defence Intelligence, and senior officials from key government departments. For over 60 years the JIC has provided regular assessments to successive Prime Ministers and senior colleagues on a wide range of foreign policy and international security issues.

Its work, like the material it analyses, is largely secret. It is unprecedented for the Government to publish this kind of document. But in light of the debate about Iraq and Weapons of Mass Destruction (WMD), I wanted to share with the British public the reasons why I believe this issue to be a current and serious threat to the UK national interest.

In recent months, I have been increasingly alarmed by the evidence from inside Iraq that despite sanctions, despite the damage done to his capability in the past, despite the UN Security Council Resolutions expressly outlawing it, and despite his denials, Saddam Hussein is continuing to develop WMD, and with them the ability to inflict real damage upon the region, and the stability of the world.

Gathering intelligence inside Iraq is not easy. Saddam's is one of the most secretive and dictatorial regimes in the world. So I believe people will understand why the Agencies cannot be specific about the sources, which have formed the judgements in this document, and why we cannot publish everything we know. We cannot, of course, publish the detailed raw intelligence. I and other Ministers have been briefed in detail on the intelligence and are satisfied as to its authority. I also want to pay tribute to our Intelligence and Security Services for the often extraordinary work that they do.

What I believe the assessed intelligence has established beyond doubt is that Saddam has continued to produce chemical and biological weapons, that he continues in his efforts to develop nuclear weapons, and that he has been able to extend the range of his ballistic missile programme. I also believe that, as stated in the document, Saddam will now do his utmost to try to conceal his weapons from UN inspectors.

The picture presented to me by the JIC in recent months has become more not less worrying. It is clear that, despite sanctions, the policy of containment has not worked sufficiently well to prevent Saddam from developing these weapons.

I am in no doubt that the threat is serious and current, that he has made progress on WMD, and that he has to be stopped.

Saddam has used chemical weapons, not only against an enemy state, but against his own people. Intelligence reports make clear that he sees the building up of his WMD capability, and the belief overseas that he would use these weapons, as vital to his

strategic interests, and in particular his goal of regional domination. And the document discloses that his military planning allows for some of the WMD to be ready within 45 minutes of an order to use them.

I am quite clear that Saddam will go to extreme lengths, indeed has already done so, to hide these weapons and avoid giving them up.

In today's inter-dependent world, a major regional conflict does not stay confined to the region in question. Faced with someone who has shown himself capable of using WMD, I believe the international community has to stand up for itself and ensure its authority is upheld.

The threat posed to international peace and security, when WMD are in the hands of a brutal and aggressive regime like Saddam's, is real. Unless we face up to the threat, not only do we risk undermining the authority of the UN, whose resolutions he defies, but more importantly and in the longer term, we place at risk the lives and prosperity of our own people.

The case I make is that the UN Resolutions demanding he stops his WMD programme are being flouted; that since the inspectors left four years ago he has continued with this programme; that the inspectors must be allowed back in to do their job properly; and that if he refuses, or if he makes it impossible for them to do their job, as he has done in the past, the international community will have to act.

I believe that faced with the information available to me, the UK Government has been right to support the demands that this issue be confronted and dealt with. We must ensure that he does not get to use the weapons he has, or get hold of the weapons he wants.

EXECUTIVE SUMMARY

1. Under Saddam Hussein Iraq developed chemical and biological weapons, acquired missiles allowing it to attack neighbouring countries with these weapons and persistently tried to develop a nuclear bomb. Saddam has used chemical weapons, both against Iran and against his own people. Following the Gulf War, Iraq had to admit to all this. And in the ceasefire of 1991 Saddam agreed unconditionally to give up his weapons of mass destruction.

2. Much information about Iraq's weapons of mass destruction is already in the public domain from UN reports and from Iraqi defectors. This points clearly to Iraq's continuing possession, after 1991, of chemical and biological agents and weapons produced before the Gulf War. It shows that Iraq has refurbished sites formerly associated with the production of chemical and biological agents. And it indicates that Iraq remains able to manufacture these agents, and to use bombs, shells, artillery rockets and ballistic missiles to deliver them.

3. An independent and well-researched overview of this public evidence was provided by the International Institute for Strategic Studies (IISS) on 9 September. The IISS report also suggested that Iraq could assemble nuclear weapons within months of obtaining fissile material from foreign sources.

4. As well as the public evidence, however, significant additional information is available to the Government from secret intelligence sources, described in more detail in this paper. This intelligence cannot tell us about everything. However, it provides a fuller picture of Iraqi plans and capabilities. It shows that Saddam Hussein attaches great importance to possessing weapons of mass destruction which he regards as the basis for Iraq's regional power. It shows that he does not regard them only as weapons of last resort. He is ready to use them, including against his own population, and is determined to retain them, in breach of United Nations Security Council Resolutions (UNSCR).

5. Intelligence also shows that Iraq is preparing plans to conceal evidence of these weapons, including incriminating documents, from renewed inspections. And it confirms that despite sanctions and the policy of containment, Saddam has continued to make progress with his illicit weapons programmes.

6. As a result of the intelligence we judge that Iraq has:

   - continued to produce chemical and biological agents;
   - military plans for the use of chemical and biological weapons, including against its own Shia population. Some of these weapons are deployable within 45 minutes of an order to use them;
   - command and control arrangements in place to use chemical and biological weapons. Authority ultimately resides with Saddam Hussein. (There is intelligence that he may have delegated this authority to his son Qusai);

- developed mobile laboratories for military use, corroborating earlier reports about the mobile production of biological warfare agents;
- pursued illegal programmes to procure controlled materials of potential use in the production of chemical and biological weapons programmes;

- tried covertly to acquire technology and materials which could be used in the production of nuclear weapons;
- sought significant quantities of uranium from Africa, despite having no active civil nuclear power programme that could require it;
- recalled specialists to work on its nuclear programme;

- illegally retained up to 20 al-Hussein missiles, with a range of 650km, capable of carrying chemical or biological warheads;
- started deploying its al-Samoud liquid propellant missile, and has used the absence of weapons inspectors to work on extending its range to at least 200km, which is beyond the limit of 150km imposed by the United Nations;
- started producing the solid-propellant Ababil-100, and is making efforts to extend its range to at least 200km, which is beyond the limit of 150km imposed by the United Nations;
- constructed a new engine test stand for the development of missiles capable of reaching the UK Sovereign Base Areas in Cyprus and NATO members (Greece and Turkey), as well as all Iraq's Gulf neighbours and Israel;
- pursued illegal programmes to procure materials for use in its illegal development of long range missiles;

- learnt lessons from previous UN weapons inspections and has already begun to conceal sensitive equipment and documentation in advance of the return of inspectors.

7. These judgements reflect the views of the Joint Intelligence Committee (JIC). More details on the judgements and on the development of the JIC's assessments since 1998 are set out in Part 1 of this paper.

8. Iraq's weapons of mass destruction are in breach of international law. Under a series of UN Security Council Resolutions Iraq is obliged to destroy its holdings of these weapons under the supervision of UN inspectors. Part 2 of the paper sets out the key UN Security Council Resolutions. It also summarises the history of the UN inspection regime and Iraq's history of deception, intimidation and concealment in its dealings with the UN inspectors.

9. But the threat from Iraq does not depend solely on the capabilities we have described. It arises also because of the violent and aggressive nature of Saddam Hussein's regime. His record of internal repression and external aggression gives rise to unique concerns about the threat he poses. The paper briefly outlines in Part 3 Saddam's rise to power, the nature of his regime and his history of regional aggression. Saddam's human rights abuses are also catalogued, including his record of torture, mass arrests and summary executions.

10. The paper briefly sets out how Iraq is able to finance its weapons programme. Drawing on illicit earnings generated outside UN control, Iraq generated illegal income of some $3 billion in 2001.

PART 1

IRAQ'S CHEMICAL, BIOLOGICAL, NUCLEAR AND BALLISTIC MISSILE PROGRAMMES

CHAPTER 1: THE ROLE OF INTELLIGENCE

1. Since UN inspectors were withdrawn from Iraq in 1998, there has been little overt information on Iraq's chemical, biological, nuclear and ballistic missile programmes. Much of the publicly available information about Iraqi capabilities and intentions is dated. But we also have available a range of secret intelligence about these programmes and Saddam Hussein's intentions. This comes principally from the United Kingdom's intelligence and analysis agencies – the Secret Intelligence Service (SIS), the Government Communications Headquarters (GCHQ), the Security Service, and the Defence Intelligence Staff (DIS). We also have access to intelligence from close allies.

2. Intelligence rarely offers a complete account of activities which are designed to remain concealed. The nature of Saddam's regime makes Iraq a difficult target for the intelligence services. Intelligence, however, has provided important insights into Iraqi programmes and Iraqi military thinking. Taken together with what is already known from other sources, this intelligence builds our understanding of Iraq's capabilities and adds significantly to the analysis already in the public domain. But intelligence sources need to be protected, and this limits the detail that can be made available.

3. Iraq's capabilities have been regularly reviewed by the Joint Intelligence Committee (JIC), which has provided advice to the Prime Minister and his senior colleagues on the developing assessment, drawing on all available sources. Part 1 of this paper includes some of the most significant views reached by the JIC between 1999 and 2002.

Joint Intelligence Committee (JIC)

The JIC is a Cabinet Committee with a history dating back to 1936. The JIC brings together the Heads of the three Intelligence and Security Agencies (Secret Intelligence Service, Government Communications Headquarters and the Security Service), the Chief of Defence Intelligence, senior policy makers from the Foreign Office, the Ministry of Defence, the Home Office, the Treasury and the Department of Trade and Industry and representatives from other Government Departments and Agencies as appropriate. The JIC provides regular intelligence assessments to the Prime Minister, other Ministers and senior officials on a wide range of foreign policy and international security issues. It meets each week in the Cabinet Office.

CHAPTER 2

IRAQ'S PROGRAMMES: 1971–1998

1. Iraq has been involved in chemical and biological warfare research for over 30 years. Its **chemical warfare** research started in 1971 at a small, well guarded site at Rashad to the north east of Baghdad. Research was conducted there on a number of chemical agents including mustard gas, CS and tabun. Later, in 1974 a dedicated organisation called al-Hasan Ibn al-Haitham was established. In the late 1970s plans were made to build a large research and commercial-scale production facility in the desert some 70km north west of Baghdad under the cover of Project 922. This was to become Muthanna State Establishment, also known as al-Muthanna, and operated under the front name of Iraq's State Establishment for Pesticide Production. It became operational in 1982-83. It had five research and development sections, each tasked to pursue different programmes. In addition, the al-Muthanna site was the main chemical agent production facility, and it also took the lead in weaponising chemical and biological agents including all aspects of weapon development and testing, in association with the military. According to information, subsequently supplied by the Iraqis, the total production capacity in 1991 was 4,000 tonnes of agent per annum, but we assess it could have been higher. Al-Muthanna was supported by three separate storage and precursor production facilities known as Fallujah 1, 2 and 3 near Habbaniyah, north west of Baghdad, parts of which were not completed before they were heavily bombed in the 1991 Gulf War.

> **Effects of Chemical Weapons**
>
> **Mustard** is a liquid agent, which gives off a hazardous vapour, causing burns and blisters to exposed skin. When inhaled, mustard damages the respiratory tract; when ingested, it causes vomiting and diarrhoea. It attacks and damages the eyes, mucous membranes, lungs, skin, and blood-forming organs.
>
> **Tabun, sarin and VX** are all nerve agents of which VX is the most toxic. They all damage the nervous system, producing muscular spasms and paralysis. As little as 10 milligrammes of VX on the skin can cause rapid death.

2. Iraq started **biological warfare** research in the mid-1970s. After small-scale research, a purpose-built research and development facility was authorised at al-Salman, also known as Salman Pak. This is surrounded on three sides by the Tigris river and situated some 35km south of Baghdad. Although some progress was made in biological weapons research at this early stage, Iraq decided to concentrate on developing chemical agents and their delivery systems at al-Muthanna. With the outbreak of the Iran-Iraq War, in the early 1980s, the biological weapons programme was revived. The appointment of Dr Rihab Taha in 1985, to head a small biological weapons research team at al-Muthanna,

The effects of biological agents

Anthrax is a disease caused by the bacterium Bacillus Anthracis. Inhalation anthrax is the manifestation of the disease likely to be expected in biological warfare. The symptoms may vary, but can include fever and internal bleeding. The incubation period for anthrax is 1 to 7 days, with most cases occurring within 2 days of exposure.

Botulinum toxin is one of the most toxic substances known to man. The first symptoms of poisoning may appear as early as 1 hour post exposure or as late as 8 days after exposure, with the incubation period between 12 and 22 hours. Paralysis leads to death by suffocation.

Aflatoxins are fungal toxins, which are potent carcinogens. Most symptoms take a long time to show. Food products contaminated by aflatoxins can cause liver inflammation and cancer. They can also affect pregnant women, leading to stillborn babies and children born with mutations.

Ricin is derived from the castor bean and can cause multiple organ failure leading to death within one or two days of inhalation.

helped to develop the programme. At about the same time plans were made to develop the Salman Pak site into a secure biological warfare research facility. Dr Taha continued to work with her team at al-Muthanna until 1987 when it moved to Salman Pak, which was under the control of the Directorate of General Intelligence. Significant resources were provided for the programme, including the construction of a dedicated production facility (Project 324) at al-Hakam. Agent production began in 1988 and weaponisation testing and later filling of munitions was conducted in association with the staff at Muthanna State Establishment. From mid-1990, other civilian facilities were taken over and some adapted for use in the production and research and development of biological agents. These included:

- al-Dawrah Foot and Mouth Vaccine Institute which produced botulinum toxin and conducted virus research. There is some intelligence to suggest that work was also conducted on anthrax;
- al-Fudaliyah Agriculture and Water Research Centre where Iraq admitted it undertook aflatoxin production and genetic engineering;
- Amariyah Sera and Vaccine Institute which was used for the storage of biological agent seed stocks and was involved in genetic engineering.

3. By the time of the Gulf War Iraq was producing very large quantities of chemical and biological agents. From a series of Iraqi declarations to the UN during the 1990s we know that by 1991 they had produced at least:
   - 19,000 litres of botulinum toxin, 8,500 litres of anthrax, 2,200 litres of aflatoxin and were working on a number of other agents;

- 2,850 tonnes of mustard gas, 210 tonnes of tabun, 795 tonnes of sarin and cyclosarin, and 3.9 tonnes of VX.

4. Iraq's **nuclear programme** was established under the Iraqi Atomic Energy Commission in the 1950s. Under a nuclear co-operation agreement signed with the Soviet Union in 1959, a nuclear research centre, equipped with a research reactor, was built at Tuwaitha, the main Iraqi nuclear research centre. The research reactor worked up to 1991. The surge in Iraqi oil revenues in the early 1970s supported an expansion of the research programme. This was bolstered in the mid-1970s by the acquisition of two research reactors powered by highly enriched uranium fuel and equipment for fuel fabrication and handling. By the end of 1984 Iraq was self-sufficient in uranium ore. One of the reactors was destroyed in an Israeli air attack in June 1981 shortly before it was to become operational; the other was never completed.

5. By the mid-1980s the deterioration of Iraq's position in the war with Iran prompted renewed interest in the military use of nuclear technology. Additional resources were put into developing technologies to enrich uranium as fissile material (material that makes up the core of a nuclear weapon) for use in nuclear weapons. Enriched uranium was preferred because it could be more easily produced covertly than the alternative, plutonium. Iraq followed parallel programmes to produce highly enriched uranium (HEU), electromagnetic isotope separation (EMIS) and gas centrifuge enrichment. By 1991 one EMIS enrichment facility was nearing completion and another was under construction. However, Iraq never succeeded in its EMIS technology and the programme had been dropped by 1991. Iraq decided to concentrate on gas centrifuges as the means for producing the necessary fissile material. Centrifuge facilities were also under construction, but the centrifuge design was still being developed. In August 1990 Iraq instigated a crash programme to develop a single nuclear weapon within a year. This programme envisaged the rapid development of a small 50 machine gas centrifuge cascade to produce weapons-grade HEU using fuel from the Soviet research reactor, which was already substantially enriched, and unused fuel from the reactor bombed by the Israelis. By the time of the Gulf War, the crash programme had made little progress.

6. Iraq's declared aim was to produce a missile warhead with a 20-kiloton yield and weapons designs were produced for the simplest implosion weapons. These were similar to the device used at Nagasaki in 1945. Iraq was also working on more

Effect of a 20-kiloton nuclear detonation

A detonation of a 20-kiloton nuclear warhead over a city might flatten an area of approximately 3 square miles. Within 1.6 miles of detonation, blast damage and radiation would cause 80% casualties, three-quarters of which would be fatal. Between 1.6 and 3.1 miles from the detonation, there would still be 10% casualties.

advanced concepts. By 1991 the programme was supported by a large body of Iraqi nuclear expertise, programme documentation and databases and manufacturing infrastructure. The International Atomic Energy Agency (IAEA) reported that Iraq had:

- experimented with high explosives to produce implosive shock waves;
- invested significant effort to understand the various options for neutron initiators;
- made significant progress in developing capabilities for the production, casting and machining of uranium metal.

SCUD missiles

The short-range mobile SCUD ballistic missile was developed by the Soviet Union in the 1950s, drawing on the technology of the German V-2 developed in World War II.

For many years it was the mainstay of Soviet and Warsaw Pact tactical missile forces and it was also widely exported. Recipients of Soviet-manufactured SCUDs included Iraq, North Korea, Iran, and Libya, although not all were sold directly by the Soviet Union.

7. Prior to the Gulf War, Iraq had a well-developed **ballistic missile** industry. Many of the missiles fired in the Gulf War were an Iraqi modified version of the SCUD missile, the al-Hussein, with an extended range of 650km. Iraq had about 250 imported SCUD-type missiles prior to the Gulf War plus an unknown number of indigenously produced engines and components. Iraq was working on other stretched SCUD variants, such as the al-Abbas, which had a range of 900km. Iraq was also seeking to reverse-engineer the SCUD engine with a view to producing new missiles. Recent intelligence indicates that they may have succeeded at that time. In particular, Iraq had plans for a new SCUD-derived missile with a range of 1200km. Iraq also conducted a partial flight test of a multi-stage satellite launch vehicle based on SCUD technology, known as the al-Abid. Also during this period, Iraq was developing the Badr-2000, a 700-1000km range two-stage solid propellant missile (based on the Iraqi part of the 1980s CONDOR-2 programme run in co-operation with Argentina and Egypt). There were plans for 1200–1500km range solid propellant follow-on systems.

The use of chemical and biological weapons

8. Iraq had made frequent use of a variety of chemical weapons during the Iran-Iraq War. Many of the casualties are still in Iranian hospitals suffering from the long-term effects of numerous types of cancer and lung diseases. In 1988 Saddam also used mustard and nerve agents against Iraqi Kurds at Halabja in northern Iraq (see box on p15). Estimates vary, but according to Human Rights Watch up to 5,000 people were killed.

9. Iraq used significant quantities of mustard, tabun and sarin during the war with Iran resulting in over 20,000 Iranian casualties. A month after the attack on Halabja, Iraqi troops used over 100 tonnes of sarin against Iranian troops on the al-Fao peninsula. Over the next three months Iraqi troops used sarin and other nerve agents on Iranian troops causing extensive casualties.

The Attack on Halabja

On Friday 17th March 1988 the village of Halabja was bombarded by Iraqi warplanes. The raid was over in minutes. Saddam Hussein used chemical weapons against his own people. A Kurd described the effects of a chemical attack on another village:

"My brothers and my wife had blood and vomit running from their noses and their mouths. Their heads were tilted to one side. They were groaning. I couldn't do much, just clean up the blood and vomit from their mouths and try in every way to make them breathe again. I did artificial respiration on them and then I gave them two injections each. I also rubbed creams on my wife and two brothers."

(From "Crimes Against Humanity" Iraqi National Congress.)



Among the corpses at Halabja, children were found dead where they had been playing outside their homes. In places, streets were piled with corpses.

10. From Iraqi declarations to the UN after the Gulf War we know that by 1991 Iraq had produced a variety of delivery means for chemical and biological agents including over 16,000 free-fall bombs and over 110,000 artillery rockets and shells. Iraq also admitted to the UN Special Commission (UNSCOM) that it had 50 chemical and 25 biological warheads available for its ballistic missiles.

The use of ballistic missiles

11. Iraq fired over 500 SCUD-type missiles at Iran during the Iran-Iraq War at both civilian and military targets, and 93 SCUD-type missiles during the Gulf War. The latter were targeted at Israel and Coalition forces stationed in the Gulf region.

12. At the end of the Gulf War the international community was determined that Iraq's arsenal of chemical and biological weapons and ballistic missiles should be dismantled. The method chosen to achieve this was the establishment of UNSCOM to carry out intrusive inspections within Iraq and to eliminate its chemical and biological weapons and ballistic missiles with a range of over 150km. The IAEA was charged with the abolition of Iraq's nuclear weapons programme. Between 1991 and 1998 UNSCOM succeeded in identifying and destroying very large quantities of chemical weapons and ballistic missiles as well as associated production facilities. The IAEA also destroyed the infrastructure for Iraq's nuclear weapons programme and removed key nuclear materials. This was achieved despite a continuous and sophisticated programme of harassment, obstruction, deception and denial (see Part 2). Because of this UNSCOM concluded by 1998 that it was unable to fulfil its mandate. The inspectors were withdrawn in December 1998.

13. Based on the UNSCOM report to the UN Security Council in January 1999 and earlier UNSCOM reports, we assess that when the UN inspectors left Iraq they were unable to account for:

    - up to 360 tonnes of bulk chemical warfare agent, including 1.5 tonnes of VX nerve agent;
    - up to 3,000 tonnes of precursor chemicals, including approximately 300 tonnes which, in the Iraqi chemical warfare programme, were unique to the production of VX;
    - growth media procured for biological agent production (enough to produce over three times the 8,500 litres of anthrax spores Iraq admits to having manufactured);
    - over 30,000 special munitions for delivery of chemical and biological agents.

14. The departure of UNSCOM meant that the international community was unable to establish the truth behind these large discrepancies and greatly diminished its ability to monitor and assess Iraq's continuing attempts to reconstitute its programmes.

CHAPTER 3

THE CURRENT POSITION: 1998–2002

1. This chapter sets out what we know of Saddam Hussein's chemical, biological, nuclear and ballistic missile programmes, drawing on all the available evidence. While it takes account of the results from UN inspections and other publicly available information, it also draws heavily on the latest intelligence about Iraqi efforts to develop their programmes and capabilities since 1998. The **main conclusions** are that:

   - Iraq has a useable chemical and biological weapons capability, in breach of UNSCR 687, which has included recent production of chemical and biological agents;
   - Saddam continues to attach great importance to the possession of weapons of mass destruction and ballistic missiles which he regards as being the basis for Iraq's regional power. He is determined to retain these capabilities;
   - Iraq can deliver chemical and biological agents using an extensive range of artillery shells, free-fall bombs, sprayers and ballistic missiles;
   - Iraq continues to work on developing nuclear weapons, in breach of its obligations under the Non-Proliferation Treaty and in breach of UNSCR 687. Uranium has been sought from Africa that has no civil nuclear application in Iraq;
   - Iraq possesses extended-range versions of the SCUD ballistic missile in breach of UNSCR 687 which are capable of reaching Cyprus, Eastern Turkey, Tehran and Israel. It is also developing longer-range ballistic missiles;
   - Iraq's current military planning specifically envisages the use of chemical and biological weapons;
   - Iraq's military forces are able to use chemical and biological weapons, with command, control and logistical arrangements in place. The Iraqi military are able to deploy these weapons within 45 minutes of a decision to do so;
   - Iraq has learnt lessons from previous UN weapons inspections and is already taking steps to conceal and disperse sensitive equipment and documentation in advance of the return of inspectors;
   - Iraq's chemical, biological, nuclear and ballistic missiles programmes are well-funded.

CHEMICAL AND BIOLOGICAL WEAPONS

Joint Intelligence Committee (JIC) Assessment: 1999–2002

2. Since the withdrawal of the inspectors the JIC has monitored evidence, including from secret intelligence, of continuing work on Iraqi offensive chemical and biological warfare capabilities. In the first half of 2000 the JIC noted

intelligence on Iraqi attempts to procure dual-use chemicals and on the reconstruction of civil chemical production at sites formerly associated with the chemical warfare programme. Iraq had also been trying to procure dual-use materials and equipment which could be used for a biological warfare programme. Personnel known to have been connected to the biological warfare programme up to the Gulf War had been conducting research into pathogens. There was intelligence that Iraq was starting to produce biological warfare agents in mobile production facilities. Planning for the project had begun in 1995 under Dr Rihab Taha, known to have been a central player in the pre-Gulf War programme. The JIC concluded that Iraq had sufficient expertise, equipment and material to produce biological warfare agents within weeks using its legitimate bio-technology facilities.

3. In mid-2001 the JIC assessed that Iraq retained some chemical warfare agents, precursors, production equipment and weapons from before the Gulf War. These stocks would enable Iraq to produce significant quantities of mustard gas within weeks and of nerve agent within months. The JIC concluded that intelligence on Iraqi former chemical and biological warfare facilities, their limited reconstruction and civil production pointed to a continuing research and development programme. These chemical and biological capabilities represented the most immediate threat from Iraqi weapons of mass destruction. Since 1998 Iraqi development of mass destruction weaponry had been helped by the absence of inspectors and the increase in illegal border trade, which was providing hard currency.

4. In the last six months the JIC has confirmed its earlier judgements on Iraqi chemical and biological warfare capabilities and assessed that Iraq has the means to deliver chemical and biological weapons.

Recent intelligence

5. Subsequently, intelligence has become available from reliable sources which complements and adds to previous intelligence and confirms the JIC assessment that Iraq has chemical and biological weapons. The intelligence also shows that the Iraqi leadership has been discussing a number of issues related to these weapons. This intelligence covers:

   - **Confirmation that chemical and biological weapons play an important role in Iraqi military thinking:** intelligence shows that Saddam attaches great importance to the possession of chemical and biological weapons which he regards as being the basis for Iraqi regional power. He believes that respect for Iraq rests on its possession of these weapons and the missiles capable of delivering them. Intelligence indicates that Saddam is determined to retain this capability and recognises that Iraqi political weight would be diminished if Iraq's military power rested solely on its conventional military forces.

   - **Iraqi attempts to retain its existing banned weapons systems:** Iraq is already taking steps to prevent UN weapons inspectors finding evidence of

its chemical and biological weapons programme. Intelligence indicates that Saddam has learnt lessons from previous weapons inspections, has identified possible weak points in the inspections process and knows how to exploit them. Sensitive equipment and papers can easily be concealed and in some cases this is already happening. The possession of mobile biological agent production facilities will also aid concealment efforts. Saddam is determined not to lose the capabilities that he has been able to develop further in the four years since inspectors left.

- **Saddam's willingness to use chemical and biological weapons:** intelligence indicates that as part of Iraq's military planning Saddam is willing to use chemical and biological weapons, including against his own Shia population. Intelligence indicates that the Iraqi military are able to deploy chemical or biological weapons within 45 minutes of an order to do so.

Chemical and biological agents: surviving stocks

6. When confronted with questions about the unaccounted stocks, Iraq has claimed repeatedly that if it had retained any chemical agents from before the Gulf War they would have deteriorated sufficiently to render them harmless. But Iraq has admitted to UNSCOM to having the knowledge and capability to add stabiliser to nerve agent and other chemical warfare agents which would prevent such decomposition. In 1997 UNSCOM also examined some munitions which had been filled with mustard gas prior to 1991 and found that they remained very toxic and showed little sign of deterioration.

7. Iraq has claimed that all its biological agents and weapons have been destroyed. No convincing proof of any kind has been produced to support this claim. In particular, Iraq could not explain large discrepancies between the amount of growth media (nutrients required for the specialised growth of agent) it procured before 1991 and the amounts of agent it admits to having manufactured. The discrepancy is enough to produce more than three times the amount of anthrax allegedly manufactured.

Chemical agent: production capabilities

8. Intelligence shows that Iraq has continued to produce chemical agent. During the Gulf War a number of facilities which intelligence reporting indicated were directly or indirectly associated with Iraq's chemical weapons effort were attacked and damaged. Following the ceasefire UNSCOM destroyed or rendered harmless facilities and equipment used in Iraq's chemical weapons programme. Other equipment was released for civilian use either in industry or academic institutes, where it was tagged and regularly inspected and monitored, or else placed under camera monitoring, to ensure that it was not being misused. This monitoring ceased when UNSCOM withdrew from Iraq in 1998. However, capabilities remain and, although the main chemical weapon production facility at al-Muthanna was completely destroyed by UNSCOM and has not been

rebuilt, other plants formerly associated with the chemical warfare programme have been rebuilt. These include the chlorine and phenol plant at Fallujah 2 near Habbaniyah. In addition to their civilian uses, chlorine and phenol are used for precursor chemicals which contribute to the production of chemical agents.

9. Other dual-use facilities, which are capable of being used to support the production of chemical agent and precursors, have been rebuilt and re-equipped. New chemical facilities have been built, some with illegal foreign assistance, and are probably fully operational or ready for production. These include the Ibn Sina Company at Tarmiyah (see figure 1), which is a chemical research centre. It undertakes research, development and production of chemicals previously imported but not now available and which are needed for Iraq's civil industry. The Director General of the research centre is Hikmat Na'im al-Jalu who prior to the Gulf War worked in Iraq's nuclear weapons programme and after the war was responsible for preserving Iraq's chemical expertise.



FIGURE 1: THE IBN SINA COMPANY AT TARMIYAH

10. Parts of the al-Qa'qa' chemical complex damaged in the Gulf War have also been repaired and are operational. Of particular concern are elements of the phosgene production plant at al-Qa'qa'. These were severely damaged during the Gulf War, and dismantled under UNSCOM supervision, but have since been rebuilt. While phosgene does have industrial uses it can also be used by itself as a chemical agent or as a precursor for nerve agent.

11. Iraq has retained the expertise for chemical warfare research, agent production and weaponisation. Most of the personnel previously involved in the programme remain in country. While UNSCOM found a number of technical manuals (so called "cook books") for the production of chemical agents and critical precursors, Iraq's claim to have unilaterally destroyed the bulk of the documentation cannot be confirmed and is almost certainly untrue. Recent intelligence indicates that Iraq is still discussing methods of concealing such documentation in order to ensure that it is not discovered by any future UN inspections.

The Problem of Dual-Use Facilities

Almost all components and supplies used in weapons of mass destruction and ballistic missile programmes are dual-use. For example, any major petrochemical or biotech industry, as well as public health organisations, will have legitimate need for most materials and equipment required to manufacture chemical and biological weapons. Without UN weapons inspectors it is very difficult therefore to be sure about the true nature of many of Iraq's facilities.

For example, Iraq has built a large new chemical complex, Project Baiji, in the desert in north west Iraq at al-Sharqat (see figure 2). This site is a former uranium enrichment facility which was damaged during the Gulf War and rendered harmless under supervision of the IAEA. Part of the site has been rebuilt, with work starting in 1992, as a chemical production complex. Despite the site being far away from populated areas it is surrounded by a high wall with watch towers and guarded by armed guards. Intelligence reports indicate that it will produce nitric acid which can be used in explosives, missile fuel and in the purification of uranium.



FIGURE 2: AL-SHARQAT CHEMICAL PRODUCTION FACILITY

Biological agent: production capabilities

12. We know from intelligence that Iraq has continued to produce biological warfare agents. As with some chemical equipment, UNSCOM only destroyed equipment that could be directly linked to biological weapons production. Iraq also has its own engineering capability to design and construct biological agent associated fermenters, centrifuges, sprayer dryers and other equipment and is judged to be self-sufficient in the technology required to produce biological weapons. The

experienced personnel who were active in the programme have largely remained in the country. Some dual-use equipment has also been purchased, but without monitoring by UN inspectors Iraq could have diverted it to their biological weapons programme. This newly purchased equipment and other equipment previously subject to monitoring could be used in a resurgent biological warfare programme. Facilities of concern include:

- the Castor Oil Production Plant at Fallujah: this was damaged in UK/US air attacks in 1998 (Operation Desert Fox) but has been rebuilt. The residue from the castor bean pulp can be used in the production of the biological agent ricin;
- the al-Dawrah Foot and Mouth Disease Vaccine Institute: which was involved in biological agent production and research before the Gulf War;
- the Amariyah Sera and Vaccine Plant at Abu Ghraib: UNSCOM established that this facility was used to store biological agents, seed stocks and conduct biological warfare associated genetic research prior to the Gulf War. It has now expanded its storage capacity.

13. UNSCOM established that Iraq considered the use of mobile biological agent production facilities. In the past two years evidence from defectors has indicated the existence of such facilities. Recent intelligence confirms that the Iraqi military have developed mobile facilities. These would help Iraq conceal and protect biological agent production from military attack or UN inspection.

Chemical and biological agents: delivery means

14. Iraq has a variety of delivery means available for both chemical and biological agents. These include:

- free-fall bombs: Iraq acknowledged to UNSCOM the deployment to two sites of free-fall bombs filled with biological agent during 1990–91. These bombs were filled with anthrax, botulinum toxin and aflatoxin. Iraq also acknowledged possession of four types of aerial bomb with various chemical agent fills including sulphur mustard, tabun, sarin and cyclosarin;
- artillery shells and rockets: Iraq made extensive use of artillery munitions filled with chemical agents during the Iran-Iraq War. Mortars can also be used for chemical agent delivery. Iraq is known to have tested the use of shells and rockets filled with biological agents. Over 20,000 artillery munitions remain unaccounted for by UNSCOM;
- helicopter and aircraft borne sprayers: Iraq carried out studies into aerosol dissemination of biological agent using these platforms prior to 1991. UNSCOM was unable to account for many of these devices. It is probable that Iraq retains a capability for aerosol dispersal of both chemical and biological agent over a large area;
- al-Hussein ballistic missiles (range 650km): Iraq told UNSCOM that it filled 25 warheads with anthrax, botulinum toxin and aflatoxin. Iraq also

developed chemical agent warheads for al-Hussein. Iraq admitted to producing 50 chemical warheads for al-Hussein which were intended for the delivery of a mixture of sarin and cyclosarin. However, technical analysis of warhead remnants has shown traces of VX degradation product which indicate that some additional warheads were made and filled with VX;

- al-Samoud/Ababil-100 ballistic missiles (range 150km plus): it is unclear if chemical and biological warheads have been developed for these systems, but given the Iraqi experience on other missile systems, we judge that Iraq has the technical expertise for doing so;

- L-29 remotely piloted vehicle programme (see figure 3): we know from intelligence that Iraq has attempted to modify the L-29 jet trainer to allow it to be used as an Unmanned Aerial Vehicle (UAV) which is potentially capable of delivering chemical and biological agents over a large area.



FIGURE 3: THE L-29 JET TRAINER

Chemical and biological warfare: command and control

15. The authority to use chemical and biological weapons ultimately resides with Saddam but intelligence indicates that he may have also delegated this authority to his son Qusai. Special Security Organisation (SSO) and Special Republican Guard (SRG) units would be involved in the movement of any chemical and biological weapons to military units. The Iraqi military holds artillery and missile systems at Corps level throughout the Armed Forces and conducts regular training with them. The Directorate of Rocket Forces has operational control of strategic missile systems and some Multiple Launcher Rocket Systems.

Chemical and biological weapons: summary

16. Intelligence shows that Iraq has covert chemical and biological weapons programmes, in breach of UN Security Council Resolution 687 and has continued to produce chemical and biological agents. Iraq has:

    - chemical and biological agents and weapons available, both from pre-Gulf War stocks and more recent production;
    - the capability to produce the chemical agents mustard gas, tabun, sarin, cyclosarin, and VX capable of producing mass casualties;

- a biological agent production capability and can produce at least anthrax, botulinum toxin, aflatoxin and ricin. Iraq has also developed mobile facilities to produce biological agents;
- a variety of delivery means available;
- military forces, which maintain the capability to use these weapons with command, control and logistical arrangements in place.

NUCLEAR WEAPONS

Joint Intelligence Committee (JIC) Assessments: 1999–2001

17. Since 1999 the JIC has monitored Iraq's attempts to reconstitute its nuclear weapons programme. In mid-2001 the JIC assessed that Iraq had continued its nuclear research after 1998. The JIC drew attention to intelligence that Iraq had recalled its nuclear scientists to the programme in 1998. Since 1998 Iraq had been trying to procure items that could be for use in the construction of centrifuges for the enrichment of uranium.

Iraqi nuclear weapons expertise

18. Paragraphs 5 and 6 of Chapter 2 describe the Iraqi nuclear weapons programme prior to the Gulf War. It is clear from IAEA inspections and Iraq's own declarations that by 1991 considerable progress had been made in both developing methods to produce fissile material and in weapons design. The IAEA dismantled the physical infrastructure of the Iraqi nuclear weapons

Elements of a nuclear weapons programme: nuclear fission weapon

A typical nuclear fission weapon consists of:

- fissile material for the core which gives out huge amounts of explosive energy from nuclear reactions when made "super critical" through extreme compression. Fissile material is usually either highly enriched uranium (HEU) or weapons-grade plutonium:
  - HEU can be made in gas centrifuges (see separate box on p25);
  - plutonium is made by reprocessing fuel from a nuclear reactor;
- explosives which are needed to compress the nuclear core. These explosives also require a complex arrangement of detonators, explosive charges to produce an even and rapid compression of the core;
- sophisticated electronics to fire the explosives;
- a neutron initiator to provide initial burst of neutrons to start the nuclear reactions.

Weaponisation

Weaponisation is the conversion of these concepts into a reliable weapon. It includes:

- developing a weapon design through sophisticated science and complex calculations;
- engineering design to integrate with the delivery system;
- specialised equipment to cast and machine safely the nuclear core;
- dedicated facilities to assemble the warheads;
- facilities to rigorously test all individual components and designs;

The complexity is much greater for a weapon that can fit into a missile warhead than for a larger Nagasaki-type bomb.

programme, including the dedicated facilities and equipment for uranium separation and enrichment, and for weapon development and production, and removed the remaining highly enriched uranium. But Iraq retained, and retains, many of its experienced nuclear scientists and technicians who are specialised in the production of fissile material and weapons design. Intelligence indicates that Iraq also retains the accompanying programme documentation and data.

19. Intelligence shows that the present Iraqi programme is almost certainly seeking an indigenous ability to enrich uranium to the level needed for a nuclear weapon. It indicates that the approach is based on gas centrifuge uranium enrichment, one of the routes Iraq was following for producing fissile material before the Gulf War. But Iraq needs certain key equipment, including gas centrifuge components and components for the production of fissile material before a nuclear bomb could be developed.

Gas centrifuge uranium enrichment

Uranium in the form of uranium hexafluoride is separated into its different isotopes in rapidly spinning rotor tubes of special centrifuges. Many hundreds or thousands of centrifuges are connected in cascades to enrich uranium. If the lighter U235 isotope is enriched to more than 90% it can be used in the core of a nuclear weapon.

20. Following the departure of weapons inspectors in 1998 there has been an accumulation of intelligence indicating that Iraq is making concerted covert efforts to acquire dual-use technology and materials with nuclear applications. Iraq's known holdings of processed uranium are under IAEA supervision. But there is intelligence that Iraq has sought the supply of significant quantities of uranium from Africa. Iraq has no active civil nuclear power programme or nuclear power plants and therefore has no legitimate reason to acquire uranium.

Iraq's civil nuclear programme

- Iraq's long-standing civil nuclear power programme is limited to small scale research. Activities that could be used for military purposes are prohibited by UNSCR 687 and 715.
- Iraq has no nuclear power plants and therefore no requirement for uranium as fuel.
- Iraq has a number of nuclear research programmes in the fields of agriculture, biology, chemistry, materials and pharmaceuticals. None of these activities requires more than tiny amounts of uranium which Iraq could supply from its own resources.
- Iraq's research reactors are non-operational; two were bombed and one was never completed.

21. Intelligence shows that other important procurement activity since 1998 has included attempts to purchase:

    - vacuum pumps which could be used to create and maintain pressures in a gas centrifuge cascade needed to enrich uranium;
    - an entire magnet production line of the correct specification for use in the motors and top bearings of gas centrifuges. It appears that Iraq is attempting to acquire a capability to produce them on its own rather than rely on foreign procurement;
    - Anhydrous Hydrogen Fluoride (AHF) and fluorine gas. AHF is commonly used in the petrochemical industry and Iraq frequently imports significant amounts, but it is also used in the process of converting uranium into uranium hexafluoride for use in gas centrifuge cascades;
    - one large filament winding machine which could be used to manufacture carbon fibre gas centrifuge rotors;
    - a large balancing machine which could be used in initial centrifuge balancing work.

22. Iraq has also made repeated attempts covertly to acquire a very large quantity (60,000 or more) of specialised aluminium tubes. The specialised aluminium in question is subject to international export controls because of its potential application in the construction of gas centrifuges used to enrich uranium, although there is no definitive intelligence that it is destined for a nuclear programme.

Nuclear weapons: timelines

23. In early 2002, the JIC assessed that UN sanctions on Iraq were hindering the import of crucial goods for the production of fissile material. The JIC judged

that while sanctions remain effective Iraq would not be able to produce a nuclear weapon. If they were removed or prove ineffective, it would take Iraq at least five years to produce sufficient fissile material for a weapon indigenously. However, we know that Iraq retains expertise and design data relating to nuclear weapons. We therefore judge that if Iraq obtained fissile material and other essential components from foreign sources the timeline for production of a nuclear weapon would be shortened and Iraq could produce a nuclear weapon in between one and two years.

BALLISTIC MISSILES

Joint Intelligence Committee (JIC) Assessment: 1999–2002

24. In mid-2001 the JIC drew attention to what it described as a "step-change" in progress on the Iraqi missile programme over the previous two years. It was clear from intelligence that the range of Iraqi missiles which was permitted by the UN and supposedly limited to 150kms was being extended and that work was under way on larger engines for longer-range missiles.

25. In early 2002 the JIC concluded that Iraq had begun to develop missiles with a range of over 1,000kms. The JIC assessed that if sanctions remained effective the Iraqis would not be able to produce such a missile before 2007. Sanctions and the earlier work of the inspectors had caused significant problems for Iraqi missile development. In the previous six months Iraqi foreign procurement efforts for the missile programme had been bolder. The JIC also assessed that Iraq retained up to 20 al-Hussein missiles from before the Gulf War.

The Iraqi ballistic missile programme since 1998

26. Since the Gulf War, Iraq has been openly developing two short-range missiles up to a range of 150km, which are permitted under UN Security Council Resolution 687. The al-Samoud liquid propellant missile has been extensively tested and is being deployed to military units. Intelligence indicates that at least 50 have been produced. Intelligence also indicates that Iraq has worked on extending its range to at least 200km in breach of UN Security Resolution 687. Production of the solid propellant Ababil-100 (Figure 4) is also underway, probably as an unguided rocket at this stage. There are also plans to extend its range to at least 200km. Compared to liquid propellant missiles, those powered by solid



FIGURE 4: ABABIL-100

propellant offer greater ease of storage, handling and mobility. They are also quicker to take into and out of action and can stay at a high state of readiness for longer periods.

27. According to intelligence, Iraq has retained up to 20 al-Hussein missiles (Figure 5), in breach of UN Security Council Resolution 687. These missiles were either hidden from the UN as complete systems, or re-assembled using illegally retained engines and other components. We judge that the engineering expertise available would allow these missiles to be maintained effectively, although the fact that at least some require re-assembly makes it difficult to judge exactly how many could be available for use. They could be used with conventional, chemical or biological warheads and, with a range of up to 650km, are capable of reaching a number of countries in the region including Cyprus, Turkey, Saudi Arabia, Iran and Israel.



FIGURE 5: AL-HUSSEIN

28. Intelligence has confirmed that Iraq wants to extend the range of its missile systems to over 1000km, enabling it to threaten other regional neighbours. This work began in 1998, although efforts to regenerate the long-range ballistic missile programme probably began in 1995. Iraq's missile programmes employ hundreds of people. Satellite imagery (Figure 6) has shown a new engine test stand being constructed (A), which is larger than the current one used for al-Samoud (B), and that formerly used for testing SCUD engines (C) which was dismantled under UNSCOM supervision. This new stand will be capable of testing engines for medium range ballistic missiles (MRBMs) with ranges over 1000km, which are not permitted under UN Security Council Resolution 687. Such a facility would not be needed for systems that fall within the UN permitted range of 150km. The Iraqis have recently taken measures to conceal activities at this site. Iraq is also working to obtain improved guidance technology to increase missile accuracy.



FIGURE 6: AL-RAFAH/SHAHIYAT LIQUID PROPELLANT ENGINE STATIC TEST STAND

29. The success of UN restrictions means the development of new longer-range missiles is likely to be a slow process. These restrictions impact particularly on the:

- availability of foreign expertise;
- conduct of test flights to ranges above 150km;
- acquisition of guidance and control technology.

30. Saddam remains committed to developing longer-range missiles. Even if sanctions remain effective, Iraq might achieve a missile capability of over 1000km within 5 years (Figure 7 shows the range of Iraq's various missiles).

31. Iraq has managed to rebuild much of the missile production infrastructure destroyed in the Gulf War and in Operation Desert Fox in 1998 (see Part 2). New missile-related infrastructure is also under construction. Some aspects of this, including rocket propellant mixing and casting facilities at the al-Mamoun Plant, appear to replicate those linked to the prohibited Badr-2000 programme (with a planned range of 700–1000km) which were destroyed in the Gulf War or dismantled by UNSCOM. A new plant at al-Mamoun for indigenously producing ammonium perchlorate, which is a key ingredient in the production of solid propellant rocket motors, has also been constructed. This has been provided illicitly by NEC Engineers Private Limited, an Indian chemical engineering firm with extensive links in Iraq, including to other suspect facilities such as the Fallujah 2 chlorine plant. After an extensive investigation, the Indian authorities have recently suspended its export licence, although other individuals and companies are still illicitly procuring for Iraq.

32. Despite a UN embargo, Iraq has also made concerted efforts to acquire additional production technology, including machine tools and raw materials, in breach of UN Security Council Resolution 1051. The embargo has succeeded in blocking many of these attempts, such as requests to buy magnesium powder and ammonium chloride. But we know from intelligence that some items have found their way to the Iraqi ballistic missile programme. More will inevitably continue to do so. Intelligence makes it clear that Iraqi procurement agents and front companies in third countries are seeking illicitly to acquire propellant chemicals for Iraq's ballistic missiles. This includes production level quantities of near complete sets of solid propellant rocket motor ingredients such as aluminium powder, ammonium perchlorate and hydroxyl terminated polybutadiene. There have also been attempts to acquire large quantities of liquid propellant chemicals such as Unsymmetrical Dimethylhydrazine (UDMH) and diethylenetriamene. We judge these are intended to support production and deployment of the al-Samoud and development of longer-range systems.

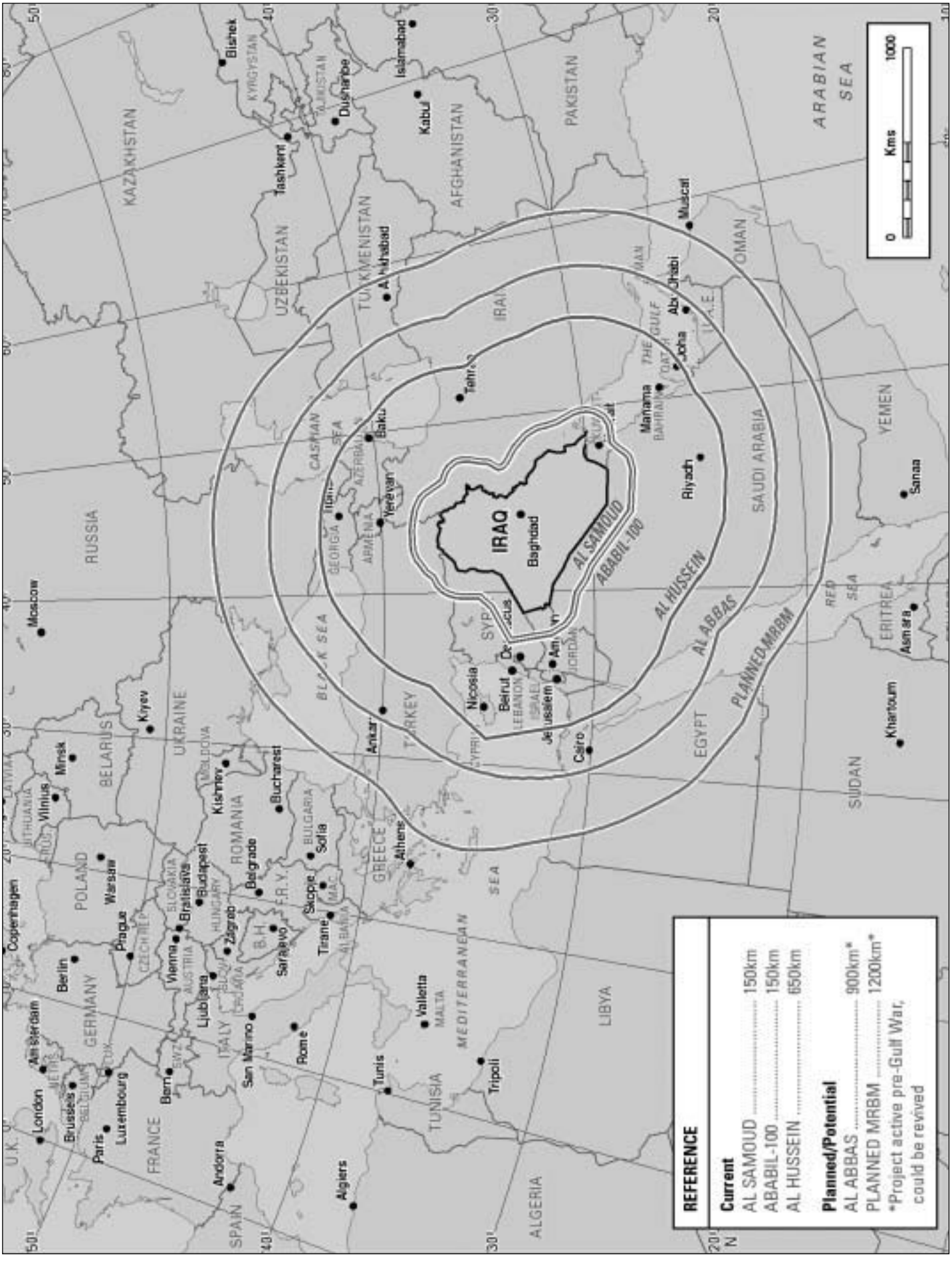


FIGURE 7: CURRENT AND PLANNED/POTENTIAL BALLISTIC MISSILES

FUNDING FOR THE WMD PROGRAMME

33. The UN has sought to restrict Iraq's ability to generate funds for its chemical, biological and other military programmes. For example, Iraq earns money legally under the UN Oil For Food Programme (OFF) established by UNSCR 986, whereby the proceeds of oil sold through the UN are used to buy humanitarian supplies for Iraq. This money remains under UN control and cannot be used for military procurement. However, the Iraqi regime continues to generate income outside UN control either in the form of hard currency or barter goods (which in turn means existing Iraqi funds are freed up to be spent on other things).

UN Sanctions

UN sanctions on Iraq prohibit all imports to and exports from Iraq. The UN must clear any goods entering or leaving. The UN also administers the Oil for Food (OFF) programme. Any imports entering Iraq under the OFF programme are checked against the Goods Review List for potential military or weapons of mass destruction utility.

34. These illicit earnings go to the Iraqi regime. They are used for building new palaces, as well as purchasing luxury goods and other civilian goods outside the OFF programme. Some of these funds are also used by Saddam Hussein to maintain his armed forces, and to develop or acquire military equipment, including for chemical, biological, nuclear and ballistic missile programmes. We do not know what proportion of these funds is used in this way. But we have seen no evidence that Iraqi attempts to develop its weapons of mass destruction and its ballistic missile programme, for example through covert procurement of equipment from abroad, has been inhibited in any way by lack of funds. The steady increase over the last three years in the availability of funds will enable Saddam to progress the programmes faster.

Iraq's illicit earnings

Year	Amount in $billions
1999	0.8 to 1
2000	1.5 to 2
2001	3
2002	3 (estimate)

PART 2

HISTORY OF UN WEAPONS INSPECTIONS

1. During the 1990s, beginning in April 1991 immediately after the end of the Gulf War, the UN Security Council passed a series of resolutions [see box] establishing the authority of UNSCOM and the IAEA to carry out the work of dismantling Iraq's arsenal of chemical, biological and nuclear weapons programmes and long-range ballistic missiles.

> **UN Security Council Resolutions relating to Weapons of Mass Destruction**
>
> **UNSCR 687, April 1991** created the UN Special Commission (UNSCOM) and required Iraq to accept, unconditionally, "the destruction, removal or rendering harmless, under international supervision" of its chemical and biological weapons, ballistic missiles with a range greater than 150km, and their associated programmes, stocks, components, research and facilities. The International Atomic Energy Agency (IAEA) was charged with abolition of Iraq's nuclear weapons programme. UNSCOM and the IAEA must report that their mission has been achieved before the Security Council can end sanctions. They have not yet done so.
>
> **UNSCR 707, August 1991,** stated that Iraq must provide full, final and complete disclosure of all its programmes for weapons of mass destruction and provide unconditional and unrestricted access to UN inspectors. For over a decade Iraq has been in breach of this resolution. Iraq must also cease all nuclear activities of any kind other than civil use of isotopes.
>
> **UNSCR 715, October 1991** approved plans prepared by UNSCOM and IAEA for the ongoing monitoring and verification (OMV) arrangements to implement UNSCR 687. Iraq did not accede to this until November 1993. OMV was conducted from April 1995 to 15 December 1998, when the UN left Iraq.
>
> **UNSCR 1051, March 1996** stated that Iraq must declare the shipment of dual-use goods which could be used for mass destruction weaponry programmes.

These resolutions were passed under Chapter VII of the UN Charter which is the instrument that allows the UN Security Council to authorise the use of military force to enforce its resolutions.

2. As outlined in UNSCR 687, Iraq's chemical, biological and nuclear weapons programmes were also a breach of Iraq's commitments under:

   - The 1925 Geneva Protocol which bans the use of chemical and biological weapons;

- the Biological and Toxin Weapons Convention which bans the development, production, stockpiling, acquisition or retention of biological weapons;
- the Nuclear Non-Proliferation Treaty which prohibits Iraq from manufacturing or otherwise acquiring nuclear weapons.

3. UNSCR 687 obliged Iraq to provide declarations on all aspects of its weapons of mass destruction programmes within 15 days and accept the destruction, removal or rendering harmless under international supervision of its chemical, biological and nuclear programmes, and all ballistic missiles with a range beyond 150km. Iraq did not make a satisfactory declaration within the specified time-frame.

   Iraq accepted the UNSCRs and agreed to co-operate with UNSCOM. The history of the UN weapons inspections was characterised by persistent Iraqi obstruction.

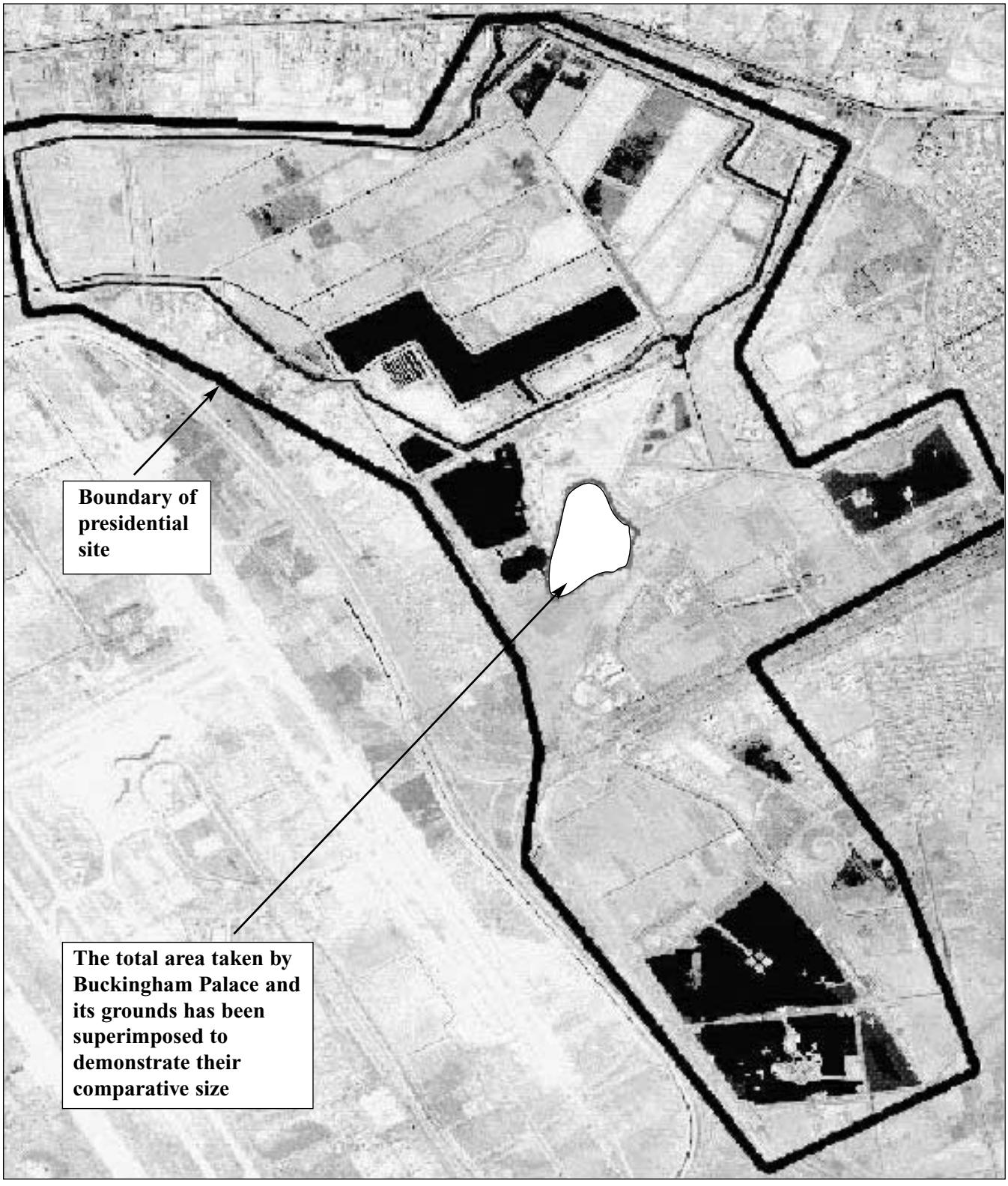
> UNSCOM and the IAEA were given the remit to designate any locations for inspection at any time, review any document and interview any scientist, technician or other individual and seize any prohibited items for destruction.

Iraqi Non-Co-operation with the Inspectors

4. The former Chairman of UNSCOM, Richard Butler, reported to the UN Security Council in January 1999 that in 1991 a decision was taken by a high-level Iraqi Government committee to provide inspectors with only a portion of its proscribed weapons, components, production capabilities and stocks. UNSCOM concluded that Iraqi policy was based on the following actions:
   - to provide only a portion of extant weapons stocks, releasing for destruction only those that were least modern;
   - to retain the production capability and documentation necessary to revive programmes when possible;
   - to conceal the full extent of its chemical weapons programme, including the VX nerve agent project; to conceal the number and type of chemical and biological warheads for proscribed long-range missiles;
   - and to conceal the existence of its biological weapons programme.

5. In December 1997 Richard Butler reported to the UN Security Council that Iraq had created a new category of sites, “Presidential” and “sovereign”, from which it claimed that UNSCOM inspectors would henceforth be barred. The terms of the ceasefire in 1991 foresaw no such limitation. However, Iraq consistently refused to allow UNSCOM inspectors access to any of these eight Presidential sites. Many of these so-called “palaces” are in fact large compounds which are an integral part of Iraqi counter-measures designed to hide weapons material (see photograph on p35).

A photograph of a "presidential site" or what have been called "palaces".



Iraq's policy of deception

Iraq has admitted to UNSCOM to having a large, effective, system for hiding proscribed material including documentation, components, production equipment and possibly biological and chemical agents and weapons from the UN. Shortly after the adoption of UNSCR 687 in April 1991, an Administrative Security Committee (ASC) was formed with responsibility for advising Saddam on the information which could be released to UNSCOM and the IAEA. The Committee consisted of senior Military Industrial Commission (MIC) scientists from all of Iraq's weapons of mass destruction programmes. The Higher Security Committee (HSC) of the Presidential Office was in overall command of deception operations. The system was directed from the very highest political levels within the Presidential Office and involved, if not Saddam himself, his youngest son, Qusai. The system for hiding proscribed material relies on high mobility and good command and control. It uses lorries to move items at short notice and most hide sites appear to be located close to good road links and telecommunications. The Baghdad area was particularly favoured. In addition to active measures to hide material from the UN, Iraq has attempted to monitor, delay and collect intelligence on UN operations to aid its overall deception plan.

Intimidation

6. Once inspectors had arrived in Iraq, it quickly became apparent that the Iraqis would resort to a range of measures (including physical threats and psychological intimidation of inspectors) to prevent UNSCOM and the IAEA from fulfilling their mandate.

7. In response to such incidents, the President of the Security Council issued frequent statements calling on Iraq to comply with its disarmament and monitoring obligations.

Iraqi obstruction of UN weapons inspection teams

- firing warning shots in the air to prevent IAEA inspectors from intercepting nuclear related equipment (June 1991);
- keeping IAEA inspectors in a car park for 4 days and refusing to allow them to leave with incriminating documents on Iraq's nuclear weapons programme (September 1991);
- announcing that UN monitoring and verification plans were "unlawful" (October 1991);
- refusing UNSCOM inspectors access to the Iraqi Ministry of Agriculture. Threats were made to inspectors who remained on watch outside the building. The inspection team had reliable evidence that the site contained archives related to proscribed activities;
- in 1991–2 Iraq objected to UNSCOM using its own helicopters and choosing its own flight plans. In January 1993 it refused to allow UNSCOM the use of its own aircraft to fly into Iraq;
- refusing to allow UNSCOM to install remote-controlled monitoring cameras at two key missile sites (June-July 1993);
- repeatedly denying access to inspection teams (1991- December 1998);
- interfering with UNSCOM's helicopter operations, threatening the safety of the aircraft and their crews (June 1997);
- demanding the end of U2 overflights and the withdrawal of US UNSCOM staff (October 1997);
- destroying documentary evidence of programmes for weapons of mass destruction (September 1997).

Obstruction

8. Iraq denied that it had pursued a biological weapons programme until July 1995. In July 1995, Iraq acknowledged that biological agents had been produced on an industrial scale at al-Hakam. Following the defection in August 1995 of Hussein Kamil, Saddam's son-in-law and former Director of the Military Industrialisation Commission, Iraq released over 2 million documents relating to its mass destruction weaponry programmes and acknowledged that it had

pursued a biological programme that led to the deployment of actual weapons. Iraq admitted producing 183 biological weapons with a reserve of agent to fill considerably more.

Inspection of Iraq's biological weapons programme

In the course of the first biological weapons inspection in August 1991, Iraq claimed that it had merely conducted a military biological research programme. At the site visited, al-Salman, Iraq had removed equipment, documents and even entire buildings. Later in the year, during a visit to the al-Hakam site, Iraq declared to UNSCOM inspectors that the facility was used as a factory to produce proteins derived from yeast to feed animals. Inspectors subsequently discovered that the plant was a central site for the production of anthrax spores and botulinum toxin for weapons. The factory had also been sanitised by Iraqi officials to deceive inspectors. Iraq continued to develop the al-Hakam site into the 1990s, misleading UNSCOM about its true purpose.

Another key site, the Foot and Mouth Disease Vaccine Institute at al-Dawrah which produced botulinum toxin and probably anthrax was not divulged as part of the programme. Five years later, after intense pressure, Iraq acknowledged that tens of tonnes of bacteriological warfare agent had been produced there and at al-Hakam.

As documents recovered in August 1995 were assessed, it became apparent that the full disclosure required by the UN was far from complete. Successive inspection teams went to Iraq to try to gain greater understanding of the programme and to obtain credible supporting evidence. In July 1996 Iraq refused to discuss its past programme and doctrine forcing the team to withdraw in protest. Monitoring teams were at the same time finding undisclosed equipment and materials associated with the past programme. In response, Iraq grudgingly provided successive disclosures of its programme which were judged by UNSCOM and specially convened international panels to be technically inadequate.

In late 1995 Iraq acknowledged weapons testing the biological agent ricin, but did not provide production information. Two years later, in early 1997, UNSCOM discovered evidence that Iraq had produced ricin.

9. Iraq tried to obstruct UNSCOM's efforts to investigate the scale of its biological weapons programme. It created forged documents to account for bacterial growth media, imported in the late 1980s, specifically for the production of anthrax, botulinum toxin and probably plague. The documents were created to indicate that the material had been imported by the State Company for Drugs and Medical Appliances Marketing for use in hospitals and distribution to local authorities. Iraq also censored documents and scientific papers provided to the first UN inspection team, removing all references to key individuals, weapons and industrial production of agents.

10. Iraq has yet to provide any documents concerning production of agent and subsequent weaponisation. Iraq destroyed, unilaterally and illegally, some biological weapons in 1991 and 1992 making accounting for these weapons impossible. In addition, Iraq cleansed a key site at al-Muthanna, its main research and development, production and weaponisation facility for chemical warfare agents, of all evidence of a biological programme in the toxicology department, the animal-house and weapons filling station.

11. Iraq refused to elaborate further on the programme during inspections in 1997 and 1998, confining discussion to previous topics. In July 1998 Tariq Aziz personally intervened in the inspection process stating that the biological programme was more secret and more closed than other mass destruction weaponry programmes. He also played down the significance of the programme. Iraq has presented the biological weapons programme as the personal undertaking of a few misguided scientists.

12. At the same time, Iraq tried to maintain its nuclear weapons programme via a concerted campaign to deceive IAEA inspectors. In 1997 the IAEA Director General stated that the IAEA was "severely hampered by Iraq's persistence in a policy of concealment and understatement of the programme's scope".

Inspection achievements

13. Despite the conduct of the Iraqi authorities towards them, both UNSCOM and the IAEA Action Team have valuable records of achievement in discovering and exposing Iraq's biological weapons programme and destroying very large quantities of chemical weapons stocks and missiles as well as the infrastructure for Iraq's nuclear weapons programme.

14. Despite UNSCOM's efforts, following the effective ejection of UN inspectors in December 1998 there remained a series of significant unresolved disarmament issues. In summarising the situation in a report to the UN Security Council, the UNSCOM Chairman, Richard Butler, indicated that:

    - contrary to the requirement that destruction be conducted under international supervision "Iraq undertook extensive, unilateral and secret destruction of large quantities of proscribed weapons and items";
    - and Iraq "also pursued a practice of concealment of proscribed items, including weapons, and a cover up of its activities in contravention of Council resolutions".

    Overall, Richard Butler declared that obstructive Iraqi activity had had "a significant impact upon the Commission's disarmament work".

UNSCOM and IAEA achievements

UNSCOM surveyed 1015 sites in Iraq, carrying out 272 separate inspections. Despite Iraqi obstruction and intimidation, UN inspectors uncovered details of chemical, biological, nuclear and ballistic missile programmes. Major UNSCOM/IAEA achievements included:

- the destruction of 40,000 munitions for chemical weapons, 2,610 tonnes of chemical precursors and 411 tonnes of chemical warfare agent;
- the dismantling of Iraq's prime chemical weapons development and production complex at al-Muthanna and a range of key production equipment;
- the destruction of 48 SCUD-type missiles, 11 mobile launchers and 56 sites, 30 warheads filled with chemical agents, and 20 conventional warheads;
- the destruction of the al-Hakam biological weapons facility and a range of production equipment, seed stocks and growth media for biological weapons;
- the discovery in 1991 of samples of indigenously-produced highly enriched uranium, forcing Iraq's acknowledgement of uranium enrichment programmes and attempts to preserve key components of its prohibited nuclear weapons programme;
- the removal and destruction of the infrastructure for the nuclear weapons programme, including the al-Athir weaponisation/testing facility.

Withdrawal of the inspectors

15. By the end of 1998 UNSCOM was in direct confrontation with the Iraqi Government which was refusing to co-operate. The US and the UK had made clear that anything short of full co-operation would make military action unavoidable. Richard Butler was requested to report to the UN Security Council in December 1998 and stated that, following a series of direct confrontations, coupled with the systematic refusal by Iraq to co-operate, UNSCOM was no longer able to perform its disarmament mandate. As a direct result on 16 December the weapons inspectors were withdrawn. Operation Desert Fox was launched by the US and the UK a few hours afterwards.

Operation Desert Fox (16–19 December 1998)

Operation Desert Fox targeted industrial facilities related to Iraq's ballistic missile programme and a suspect biological warfare facility as well as military airfields and sites used by Iraq's security organisations which are involved in its weapons of mass destruction programmes. Key facilities associated with Saddam Hussein's ballistic missile programme were significantly degraded.

The situation since 1998

16. There have been no UN-mandated weapons inspections in Iraq since 1998. In an effort to enforce Iraqi compliance with its disarmament and monitoring obligations, the UN Security Council passed Resolution 1284 in December 1999. This established the United Nations Monitoring, Verification and Inspection Commission (UNMOVIC) as a successor organisation to UNSCOM and called on Iraq to give UNMOVIC inspectors "immediate, unconditional and unrestricted access to any and all areas, facilities, equipment, records and means of transport". It also set out the steps Iraq needed to take in return for the eventual suspension and lifting of sanctions. A key measure of Iraqi compliance would be full co-operation with UN inspectors, including unconditional, immediate and unrestricted access to any and all sites, personnel and documents.

17. For the past three years, Iraq has allowed the IAEA to carry out an annual inspection of a stockpile of nuclear material (depleted natural and low-enriched uranium). This has led some countries and western commentators to conclude erroneously that Iraq is meeting its nuclear disarmament and monitoring obligations. As the IAEA has pointed out in recent weeks, this annual inspection does "not serve as a substitute for the verification activities required by the relevant resolutions of the UN Security Council".

18. Dr Hans Blix, the Executive Chairman of UNMOVIC, and Dr Mohammed El-Baradei, the Director General of the IAEA, have declared that in the absence of inspections it is impossible to verify Iraqi compliance with its UN disarmament and monitoring obligations. In April 1999 an independent UN panel of experts noted that "the longer inspection and monitoring activities remain suspended, the more difficult the comprehensive implementation of Security Council resolutions becomes, increasing the risk that Iraq might reconstitute its proscribed weapons programmes".

19. The departure of the inspectors greatly diminished the ability of the international community to monitor and assess Iraq's continuing attempts to reconstitute its chemical, biological, nuclear and ballistic missile programmes.

PART 3

IRAQ UNDER SADDAM HUSSEIN

Introduction

1. The Republic of Iraq is bounded by Turkey, Iran, Kuwait, Saudia Arabia, Jordan, Syria and the Persian Gulf. Its population of around 23 million is ethnically and religiously diverse. Approximately 77% are Arabs. Sunni Muslims form around 17% of the Arab population and dominate the government. About 60% of Iraqis are Shias and 20% are Kurds. The remaining 3% of the population consists of Assyrians, Turkomans, Armenians, Christians and Yazidis.

> **Saddam Hussein's rise to power**
>
> Saddam Hussein was born in 1937 in the Tikrit district, north of Baghdad. In 1957 he joined the Ba'ath Party. After taking part in a failed attempt to assassinate the Iraqi President, Abdul Karim Qasim, Saddam escaped, first to Syria and then to Egypt. In his absence he was sentenced to 15 years imprisonment.
>
> Saddam returned to Baghdad in 1963 when the Ba'ath Party came to power. He went into hiding after the Ba'ath fell from power later that year. He was captured and imprisoned, but in 1967 escaped and took over responsibility for Ba'ath security. Saddam set about imposing his will on the Party and establishing himself at the centre of power.
>
> The Ba'ath Party returned to power in 1968. In 1969 Saddam became Vice-Chairman of the Revolutionary Command Council, Deputy to the President, and Deputy Secretary General of the Regional Command of the Ba'ath. In 1970 he joined the Party's National Command and in 1977 was elected Assistant Secretary General. In July 1979, he took over the Presidency of Iraq. Within days, five fellow members of the Revolutionary Command Council were accused of involvement in a coup attempt. They and 17 others were summarily executed.

2. Public life in Iraq is nominally dominated by the Ba'ath Party (see box on p44). But all real authority rests with Saddam and his immediate circle. Saddam's family, tribe and a small number of associates remain his most loyal supporters. He uses them to convey his orders, including to members of the government.

3. Saddam uses patronage and violence to motivate his supporters and to control or eliminate opposition. Potential rewards include social status, money and better access to goods. Saddam's extensive security apparatus and Ba'ath Party network provides oversight of Iraqi society, with informants in social, government and military organisations. Saddam practises torture, execution and

other forms of coercion against his enemies, real or suspected. His targets are not only those who have offended him, but also their families, friends or colleagues.

The Iraqi Ba'ath Party

The Ba'ath Party is the only legal political party in Iraq. It pervades all aspects of Iraqi life. Membership, around 700,000, is necessary for self-advancement and confers benefits from the regime.

4. Saddam acts to ensure that there are no other centres of power in Iraq. He has crushed parties and ethnic groups, such as the communists and the Kurds, which might try to assert themselves. Members of the opposition abroad have been the targets of assassination attempts conducted by Iraqi security services.

Saddam Hussein's security apparatus

Saddam relies on a long list of security organisations with overlapping responsibilities. The main ones are:

- The **Special Security Organisation** oversees Saddam's security and monitors the loyalty of other security services. Its recruits are predominantly from Tikrit.
- The **Special Republican Guard** is equipped with the best available military equipment. Its members are selected on the basis of loyalty to the regime.
- The **Directorate of General Security** is primarily responsible for countering threats from the civilian population.
- The **Directorate of General Intelligence** monitors and suppresses dissident activities at home and abroad.
- The **Directorate of Military Intelligence's** role includes the investigation of military personnel.
- The **Saddam Fidayeen**, under the control of Saddam's son Udayy, has been used to deal with civil disturbances.

5. Army officers are an important part of the Iraqi government's network of informers. Suspicion that officers have ambitions other than the service of the President leads to immediate execution. It is routine for Saddam to take pre-emptive action against those who he believes might conspire against him.

Internal Repression – the Kurds and the Shias

6. Saddam has pursued a long-term programme of persecution of the Iraqi Kurds, including through the use of chemical weapons. During the Iran-Iraq war, Saddam appointed his cousin, Ali Hasan al-Majid, as his deputy in the north. In

1987-88, al-Majid led the "Anfal" campaign of attacks on Kurdish villages. Amnesty International estimates that more than 100,000 Kurds were killed or disappeared during this period.

Repression and control: some examples

- A campaign of mass arrests and killing of Shia activists led to the execution of the Ayatollah Baqir al-Sadr and his sister in April 1980.
- In 1983 80 members of another leading Shia family were arrested. Six of them, all religious leaders, were executed.
- A massive chemical weapons attack on Kurds in Halabja town in March 1988 killing 5000 and injuring 10,000 more.
- A large number of officers from the Jabbur tribe were executed in the early 1990s for the alleged disloyalty of a few of them.

7. After the Gulf War in 1991 Kurds in the north of Iraq rose up against Baghdad's rule. In response the Iraqi regime killed or imprisoned thousands, prompting a humanitarian crisis. Over a million Kurds fled into the mountains and tried to escape Iraq.

8. Persecution of Iraq's Kurds continues, although the protection provided by the northern No-Fly Zone has helped to curb the worst excesses. But outside this zone the Baghdad regime has continued a policy of persecution and intimidation.

9. The regime has used chemical weapons against the Kurds, most notably in an attack on the town of Halabja in 1988 (see Part 1 Chapter 2 paragraph 9). The implicit threat of the use of chemical weapons against the Kurds and others is an important part of Saddam's attempt to keep the civilian population under control.

10. The regime has tried to displace the traditional Kurdish and Turkoman populations of the areas under its control, primarily in order to weaken Kurdish claims to the oil-rich area around the northern city of Kirkuk. Kurds and other non-Arabs are forcibly ejected to the three northern Iraqi governorates, Dohuk, Arbil and Sulaimaniyah, which are under de facto Kurdish control. According to the United Nations Commission on Human Rights (UNCHR) Special Rapporteur for Iraq, 94,000 individuals have been expelled since 1991. Agricultural land owned by Kurds has been confiscated and redistributed to Iraqi Arabs. Arabs from southern Iraq have been offered incentives to move into the Kirkuk area.

11. After the 1979 revolution that ousted the Shah in Iran, Saddam intensified a campaign against the Shia Muslim majority of Iraq, fearing that they might be encouraged by the new Shia regime in Iran.

12. On 1 March 1991, in the wake of the Gulf War, riots broke out in the southern city of Basra, spreading quickly to other cities in Shia-dominated southern Iraq.

The regime responded by killing thousands. Many Shia tried to escape to Iran and Saudi Arabia.

13. Some of the Shia hostile to the regime sought refuge in the marshland of southern Iraq. In order to subjugate the area, Saddam embarked on a large-scale programme to drain the marshes to allow Iraqi ground forces to eliminate all opposition there. The rural population of the area fled or were forced to move to southern cities or across the border into Iran.

Saddam Hussein's Wars

14. As well as ensuring his absolute control inside Iraq, Saddam has tried to make Iraq the dominant power of the region. In pursuit of these objectives he has led Iraq into two wars of aggression against neighbours, the Iran-Iraq war and the invasion of Kuwait.

15. With the fall of the Shah in Iran in 1979, relations between Iran and Iraq deteriorated sharply. In September 1980 Saddam renounced a border treaty he had agreed with Iran in 1975 ceding half of the Shatt al-Arab waterway to Iran. Shortly thereafter, Saddam launched a large-scale invasion of Iran. He believed that he could take advantage of the state of weakness, isolation and disorganisation he perceived in post-revolutionary Iran. He aimed to seize territory, including that ceded to Iran a few years earlier, and to assert Iraq's position as a leader of the Arab world. Saddam expected it to be a short, sharp campaign. But the conflict lasted for eight years. Iraq fired over 500 ballistic missiles at Iranian targets, including major cities.

Opposition to Saddam during the Iran-Iraq war

During the war Saddam's security apparatus ensured that any internal dissent or opposition was quickly eliminated. In 1982 he quickly purged a group within Iraq's ruling clique which had suggested that the war might be brought to an end more quickly if Saddam stood down.

16. It is estimated that the Iran-Iraq war cost the two sides a million casualties. Iraq used chemical weapons extensively from 1984. Some twenty thousand Iranians were killed by mustard gas and the nerve agents tabun and sarin, all of which Iraq still possesses. The UN Security Council considered the report prepared by a team of three specialists appointed by the UN Secretary General in March 1986, following which the President made a statement condemning Iraqi use of chemical weapons. This marked the first time a country had been named for violating the 1925 Geneva Convention banning the use of chemical weapons.

17. The cost of the war ran into hundreds of billions of dollars for both sides. Iraq gained nothing. After the war ended, Saddam resumed his previous pursuit of primacy in the Gulf. His policies involved spending huge sums of money on new

military equipment. But Iraq was burdened by debt incurred during the war and the price of oil, Iraq's only major export, was low.

18. By 1990 Iraq's financial problems were severe. Saddam looked at ways to press the oil-producing states of the Gulf to force up the price of crude oil by limiting production and waive the $40 billion that they had loaned Iraq during its war with Iran. Kuwait had made some concessions over production ceilings. But Saddam blamed Kuwait for over-production. When his threats and blandishments failed, Iraq invaded Kuwait on 2 August 1990. He believed that occupying Kuwait could prove profitable.

Abuses by Iraqi forces in Kuwait

- Robbery and rape of Kuwaitis and expatriates.
- Summary executions.
- People dragged from their homes and held in improvised detention centres.
- Amnesty International has listed 38 methods of torture used by the Iraqi occupiers. These included beatings, breaking of limbs, extracting finger and toenails, inserting bottle necks into the rectum, and subjecting detainees to mock executions.
- Kuwaiti civilians arrested for "crimes" such as wearing beards.

19. Saddam also sought to justify the conquest of Kuwait on other grounds. Like other Iraqi leaders before him, he claimed that, as Kuwait's rulers had come under the jurisdiction of the governors of Basra in the time of the Ottoman Empire, Kuwait should belong to Iraq.

20. During its occupation of Kuwait, Iraq denied access to the Red Cross, which has a mandate to provide protection and assistance to civilians affected by international armed conflict. The death penalty was imposed for relatively minor "crimes" such as looting and hoarding food.

21. In an attempt to deter military action to expel it from Kuwait, the Iraqi regime took hostage several hundred foreign nationals (including children) in Iraq and Kuwait and prevented thousands more from leaving, in direct contravention of international humanitarian law. Hostages were held as human shields at a number of strategic military and civilian sites.

22. At the end of the Gulf War, the Iraqi army fleeing Kuwait set fire to over 1,160 Kuwaiti oil wells with serious environmental consequences.

23. More than 600 Kuwaiti and other prisoners of war and missing persons are still unaccounted for. Iraq refuses to comply with its UN obligation to account for the missing. It has provided sufficient information to close only three case-files.

Abuse of human rights

24. This section draws on reports of human rights abuses from authoritative international organisations, including Amnesty International and Human Rights Watch.

25. Human rights abuses continue within Iraq. People continue to be arrested and detained on suspicion of political or religious activities or often because they are related to members of the opposition. Executions are carried out without due process of law. Relatives are often prevented from burying the victims in accordance with Islamic practice. Thousands of prisoners have been executed.

Human rights: abuses under Saddam Hussein

- 4000 prisoners were executed at Abu Ghraib Prison in 1984.
- 3000 prisoners were executed at the Mahjar Prison between 1993 and 1998.
- About 2500 prisoners were executed between 1997 and 1999 in a "prison cleansing" campaign.
- 122 male prisoners were executed at Abu Ghraib prison in February/ March 2000. A further 23 political prisoners were executed there in October 2001.
- In October 2000 dozens of women accused of prostitution were beheaded without any judicial process. Some were accused for political reasons.
- Women prisoners at Mahjar are routinely raped by their guards.
- Methods of torture used in Iraqi jails include using electric drills to mutilate hands, pulling out fingernails, knife cuts, sexual attacks and 'official rape'.
- Prisoners at the Qurtiyya Prison in Baghdad and elsewhere are kept in metal boxes the size of tea chests. If they do not confess they are left to die.

26. Saddam has issued a series of decrees establishing severe penalties for criminal offences. These include amputation, branding, cutting off ears, and other forms of mutilation. Anyone found guilty of slandering the President has their tongue removed.

Human Rights – mistreatment in Abu Ghraib Prison

Abdallah, a member of the Ba'ath Party whose loyalty became suspect was imprisoned for four years at Abu Ghraib in the 1980s. On the second day of his imprisonment, the men were forced to walk between two rows of five guards each to receive their containers of food. While walking to get the food, they were beaten by the guards with plastic telephone cables. They had to return to their cells the same way, so that a walk to get breakfast resulted in twenty lashes. According to Abdallah, "It wasn't that bad going to get the food, but coming back the food was spilled when we were beaten." The same procedure was used when the men went to the bathroom. On the third day, the torture continued. "We were removed from our cells and beaten with plastic pipes. This surprised us, because we were asked no question. Possibly it was being done to break our morale", Abdallah speculated. The torture escalated to sixteen sessions daily. The treatment was organised and systematic. Abdallah was held alone in a 3x2-meter room that opened onto a corridor. "We were allowed to go to the toilet three times a day, then they reduced the toilet to once a day for only one minute. I went for four years without a shower or a wash", Abdallah said. He also learned to cope with the deprivation and the hunger that accompanied his detention: "I taught myself to drink a minimum amount of water because there was no placed to urinate. They used wooden sticks to beat us and sometimes the sticks would break. I found a piece of a stick, covered with blood, and managed to bring it back to my room. I ate it for three days. A person who is hungry can eat anything. Pieces of our bodies started falling off from the beatings and our skin was so dry that it began to fall off. I ate pieces of my own body. "No one, not Pushkin, not Mahfouz, can describe what happened to us. It is impossible to describe what living this day to day was like. I was totally naked the entire time. Half of the original groups [of about thirty men] died. It was a slow type of continuous physical and psychological torture. Sometimes, it seemed that orders came to kill one of us, and he would be beaten to death". *(Source: Human Rights Watch)*

Saddam Hussein's family

27. Saddam's son Udayy maintained a private torture chamber known as the Red Room in a building on the banks of the Tigris disguised as an electricity installation. He created a militia in 1994 which has used swords to execute victims outside their own homes. He has personally executed dissidents, for instance in the Shia uprising at Basra which followed the Gulf War.

28. Members of Saddam's family are also subject to persecution. A cousin of Saddam, Ala Abd al-Qadir al-Majid, fled to Jordan from Iraq citing disagreements with the regime over business matters. He returned to Iraq after the Iraqi Ambassador in Jordan declared publicly that his life was not in danger. He was met at the border by Tahir Habbush, Head of the Directorate of General Intelligence (the Mukhabarat), and taken to a farm owned by Ali Hasan al-Majid. At the farm Ala was tied to a tree and executed by members of his immediate family who, following orders from Saddam, took it in turns to shoot him

29. Some 40 of Saddam's relatives, including women and children, have been killed. His sons-in-law Hussein and Saddam Kamil had defected in 1995 and returned to Iraq from Jordan after the Iraqi government had announced amnesties for them. They were executed in February 1996.

Human Rights –individual testimony

In December 1996, a Kurdish businessman from Baghdad was arrested outside his house by plainclothes security men. Initially his family did not know his whereabouts and went from one police station to another inquiring about him. Then they found out that he was being held in the headquarters of the General Security Directorate in Baghdad. The family was not allowed to visit him. Eleven months later the family was told by the authorities that he had been executed and that they should go and collect his body. His body bore evident signs of torture. His eyes were gouged out and the empty eye sockets filled with paper. His right wrist and left leg were broken. The family was not given any reason for his arrest and subsequent execution. However, they suspected that he was executed because of his friendship with a retired army general who had links with the Iraqi opposition outside the country and who was arrested just before his arrest and also executed. *(Source: Amnesty International)*

Human Rights – individual testimony

"…I saw a friend of mine, al-Shaikh Nasser Taresh al-Sa'idi, naked. He was handcuffed and a piece of wood was placed between his elbows and his knees. Two ends of the wood were placed on two high chairs and al-Shaikh Nasser was being suspended like a chicken. This method of torture is known as al-Khaygania (a reference to a former security director known as al-Khaygani). An electric wire was attached to al-Shaikh Nasser's penis and another one attached to one of his toes. He was asked if he could identify me and he said "this is al-Shaikh Yahya". They took me to another room and then after about 10 minutes they stripped me of my clothes and a security officer said "the person you saw has confessed against you". He said to me "You followers of [Ayatollah] al-Sadr have carried out acts harmful to the security of the country and have been distributing anti-government statements coming from abroad". He asked if I have any contact with an Iraqi religious scholar based in Iran who has been signing these statements. I said "I do not have any contacts with him"… I was then left suspended in the same manner as al-Shaikh al-Sa'idi. My face was looking upward. They attached an electric wire on my penis and the other end of the wire is attached to an electric motor. One security man was hitting my feet with a cable. Electric shocks were applied every few minutes and were increased. I must have been suspended for more than an hour. I lost consciousness. They took me to another room and made me walk even though my feet were swollen from beating… They repeated this method a few times." *(Source: Amnesty International, testimony from an Iraqi theology student from Saddam City)*

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CRITICAL NUCLEAR WEAPON DESIGN INFORMATION
-- DOD DIRECTIVE 5210.2 APPLIES –

NUCLEAR WEAPON DATA

SIGMA 8

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
1ST REVIEW-DATE: 5/25/96 DETERMINATION (CIRCLE NUMBER(S))
AUTHORITY: DC DD
NAME: R. Jund & Cuner
SCA
2ND REVIEW-DATE: 11/1/99
AUTHORITY: DD
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2. CLASSIFICATION CHANGED TO:
3. CONTAINS NO DOE CLASSIFIED INFO
4. COORDINATE WITH: DoD
5. CLASSIFICATION CANCELED
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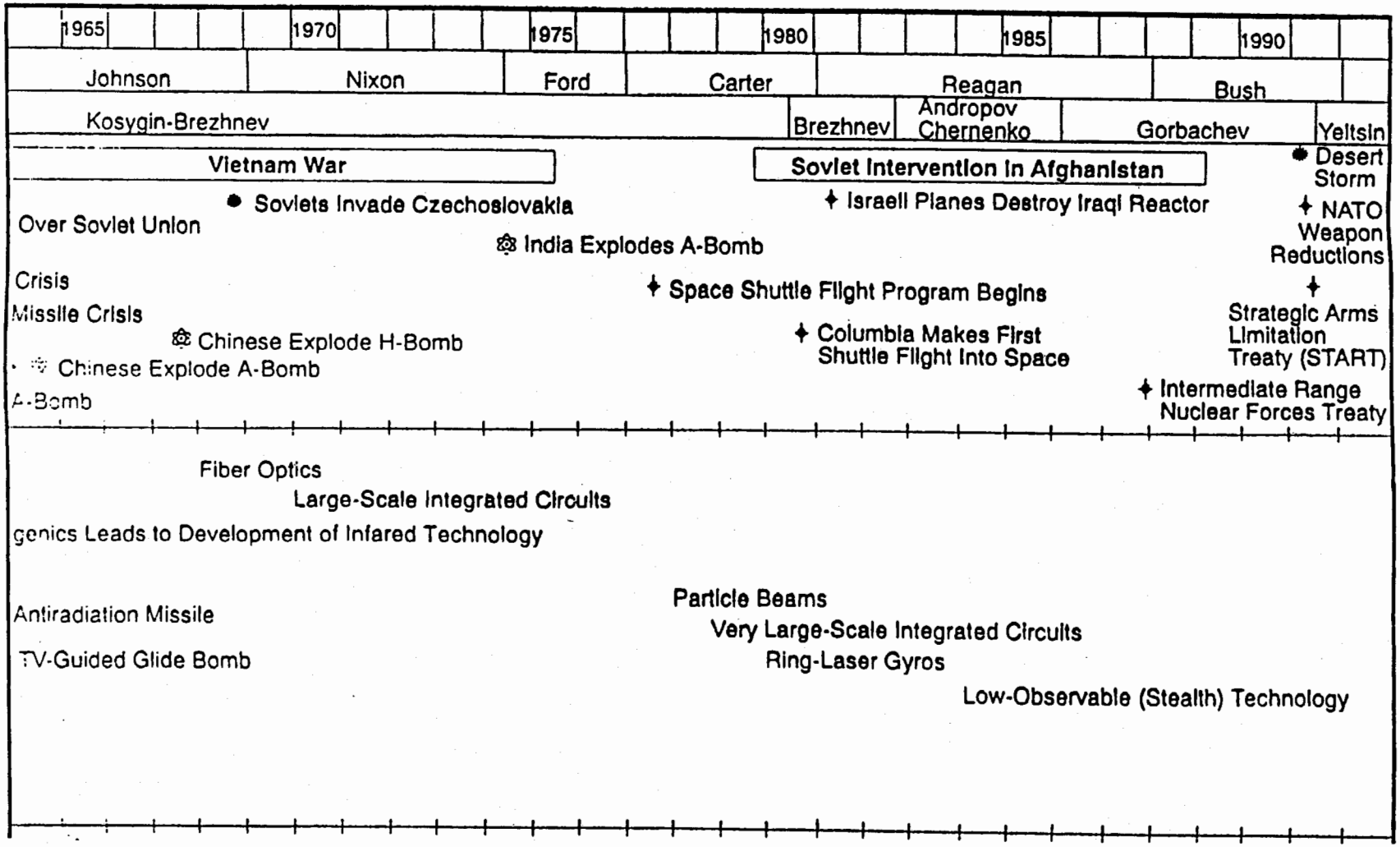
National Security Strategy: Deterrence

Decade	Implementation
1950	Massive Retaliation
1960	Flexible Response
1970	Flexible Response
1980	Flexible Response
1990	Last Resort

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SIGNIFICANT HISTORICAL EVENTS RELATIVE TO NUCLEAR WEAPONS



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Strategy, Arms Control, and Weapon Systems Technology Drive Stockpile Requirements

Strategy	Threat	Tech.	Size/Wt.	Yield	Arms Control	Number
1950 Massive retaliation	Global	A/C & missiles inaccurate	Large	Very high	Very limited talks	Growing
1960 Flexible response	Global Theater	A/C & missiles improve	Decrease	Decrease	Limited talks	Growing
1970 Flexible response	Global Theater	A/C & missiles improve accuracy	Decrease even more	Tactical needed lower yields	SALT ABM limitations	Decline
1980 Flexible response	Global Theater	A/C & missiles very accurate	Large decrease	Continued decrease	Mutual elimination & reduce	Decline more
1990 Last resort	Theater Global	A/C & missiles very accurate	Remain small	Remain same	Large cuts mutual elimination/ unilateral	Large reduction

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WEAPON DEVELOPMENT

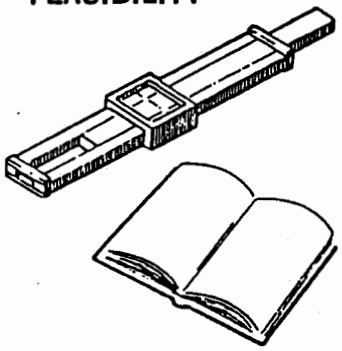
PHASE 1

CONCEPT DEFINITION



PHASE 2

FEASIBILITY



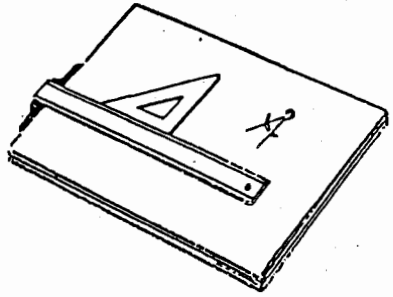
PHASE 2A

DESIGN DEFINITION AND COST



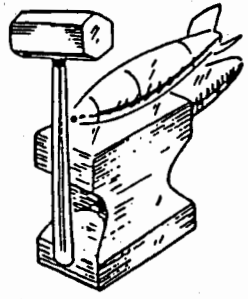
PHASE 3

DEVELOPMENT ENGINEERING



PHASE 4

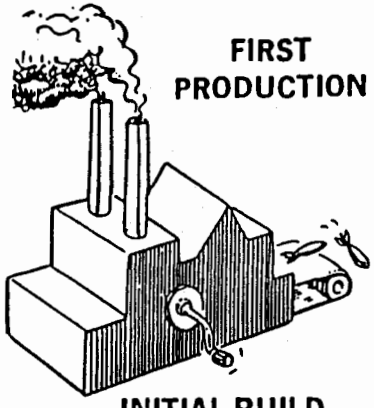
PRODUCTION ENGINEERING



PILOT PRODUCTION & TOOL MADE SAMPLE

PHASE 5

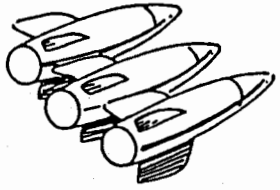
FIRST PRODUCTION



INITIAL BUILD AND EVALUATION

PHASE 6

QUANTITY PRODUCTION & STOCKPILE



INITIAL OPERATIONAL CAPABILITY (IOC)

PHASE 7

RETIREMENT



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- AN INTRODUCTION TO NUCLEAR WEAPONS; WASH 1037 REVISED, GLASSTONE, JUNE 1972

- SOURCE BOOK ON ATOMIC ENERGY; GLASSTONE, 3rd EDITION

- NUCLEAR TEST SUMMARY TRINITY — HARDTACK DASA 1220; RS3141/10349

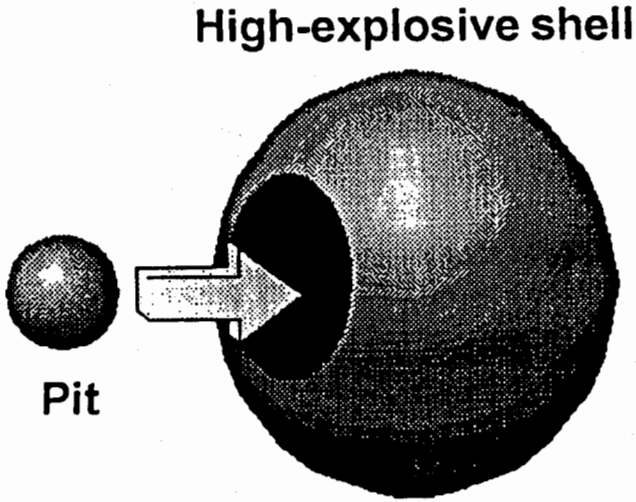
- VARIOUS WEAPON DEVELOPMENT REPORTS

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Manually Inserted Capsules

1948 - 1951

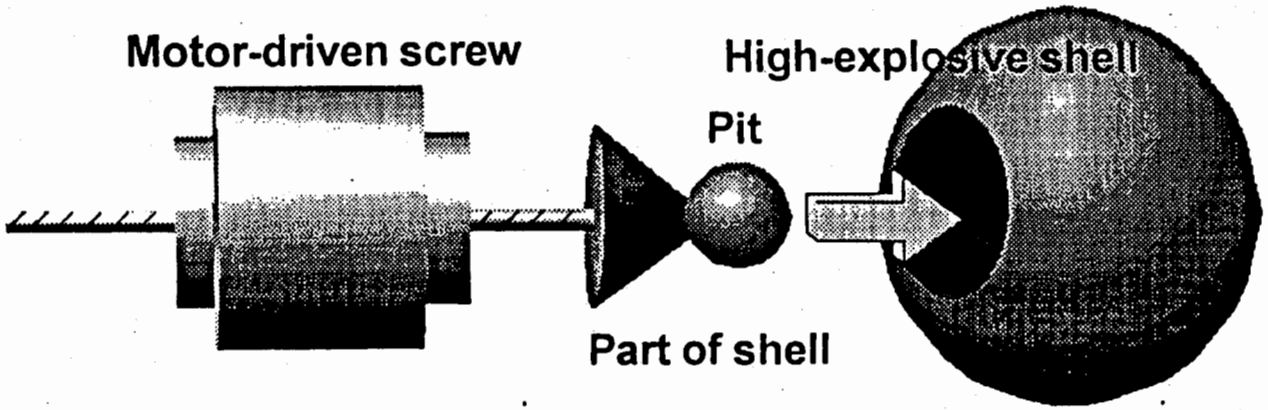


- Safety Theme: Separation of fissile material and HE
- Analysis: Accident must assemble weapon

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Mechanically Inserted Capsules

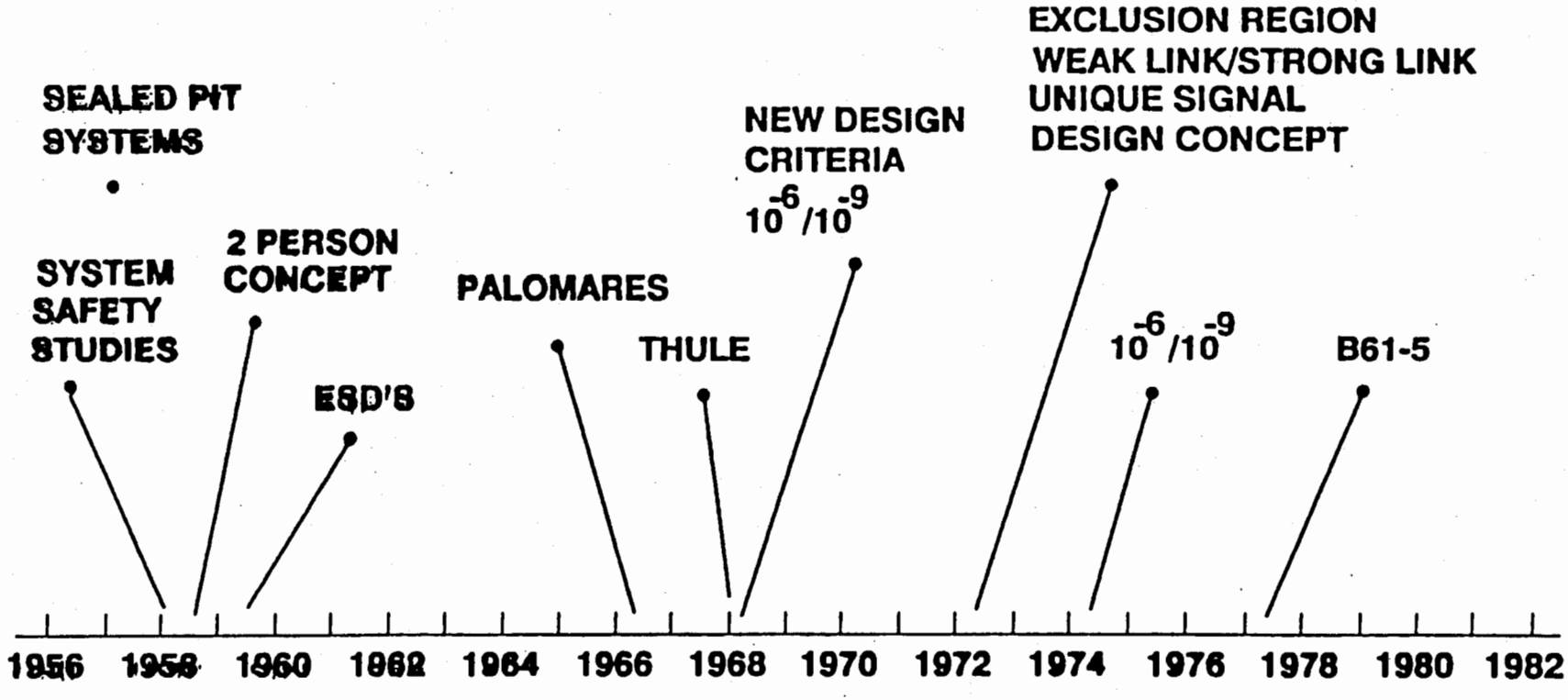
1952 - 1967



- Safety Theme: Separation of fissile material and HE and electrical isolation
- Analysis: Accident could assemble weapon by operating motor or by mechanical damage

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EVOLUTION OF NUCLEAR SAFETY



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Early Electrical Isolation Safety Features

1950 - 1970

- Removable safing plugs
- Circuit board and cable isolation
- Removable or external power supplies
- Ready-safe switches
- Thermal fuses
- Environmental sensing devices

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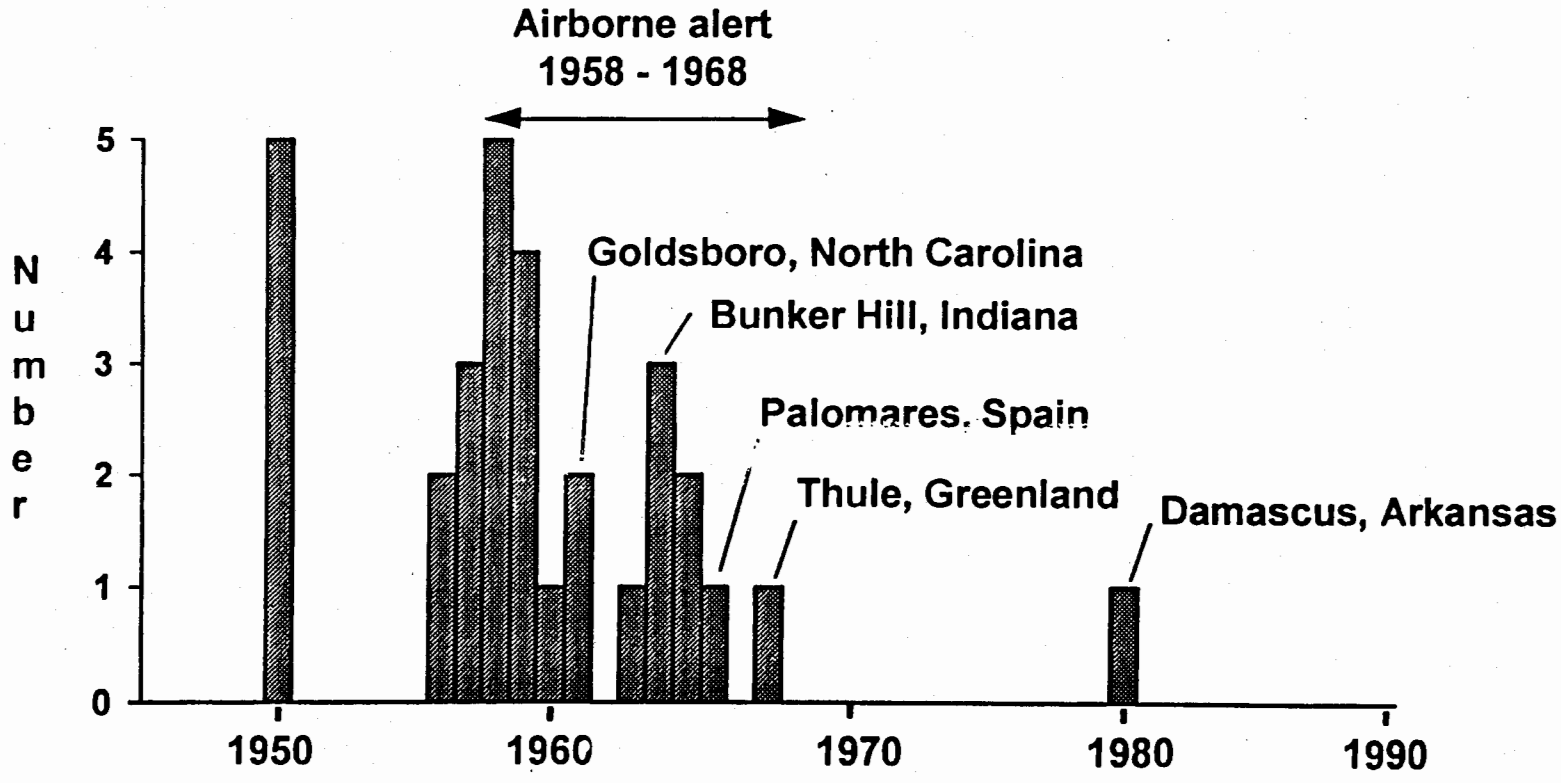
Environmental Sensing Devices (ESDs)

An open switch in the prearming circuits.

It is closed after sensing an environment experiences by the weapon system when enroute to the target.

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US Nuclear Weapon Accidents



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Nuclear Weapon Accident--Definition

DOD Directive 5100.52

"An unexpected event involving nuclear weapons or nuclear components that results in any of the following:

(1) Accidental or unauthorized launching, firing, or use by U.S. forces or U.S. supported allied forces of a nuclear capable weapon system.

(2) An accidental, unauthorized, or unexplained nuclear detonation.

(3) Non-nuclear detonation or burning of a nuclear weapon or nuclear component.

(4) Radioactive contamination.

(5) Jettisoning of a nuclear weapon or nuclear component.

(6) Public hazard, actual or perceived."

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Accidents (mainly air-delivered systems) eventually led to reexamination of the premature nuclear yield criteria and to the present nuclear detonation safety design criteria.

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Need for a Safety Process

- As the deployment dates for sealed pit weapons approached, the Armed Forces Special Weapons Project (AFSWP) and the Services became uncomfortable with their lack of knowledge and understanding of weapon safety designs.

- 1957, AFSWP convened a safety Board to examine the sealed pit weapon systems becoming available.

- Between 1957 and 1960, the Air Force convened joint safety study groups as weapons entered the stockpile.

- A formal, Joint DoD/DOE Nuclear Weapons System Safety process was established in 1960.

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DoD/DOE Nuclear Weapon Safety Process

- Joint Safety Study of Each Weapon System and Operational Concept

  - Determine if Weapon System Meets the 4 Qualitative Standards

  - Develop Operation Safety Rules

  and

  - Ensure Maximum Safety Consistent with Operational Requirements

SECRET/RD
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Conclusion of Stockpile Study

New approach to nuclear weapon safety needed

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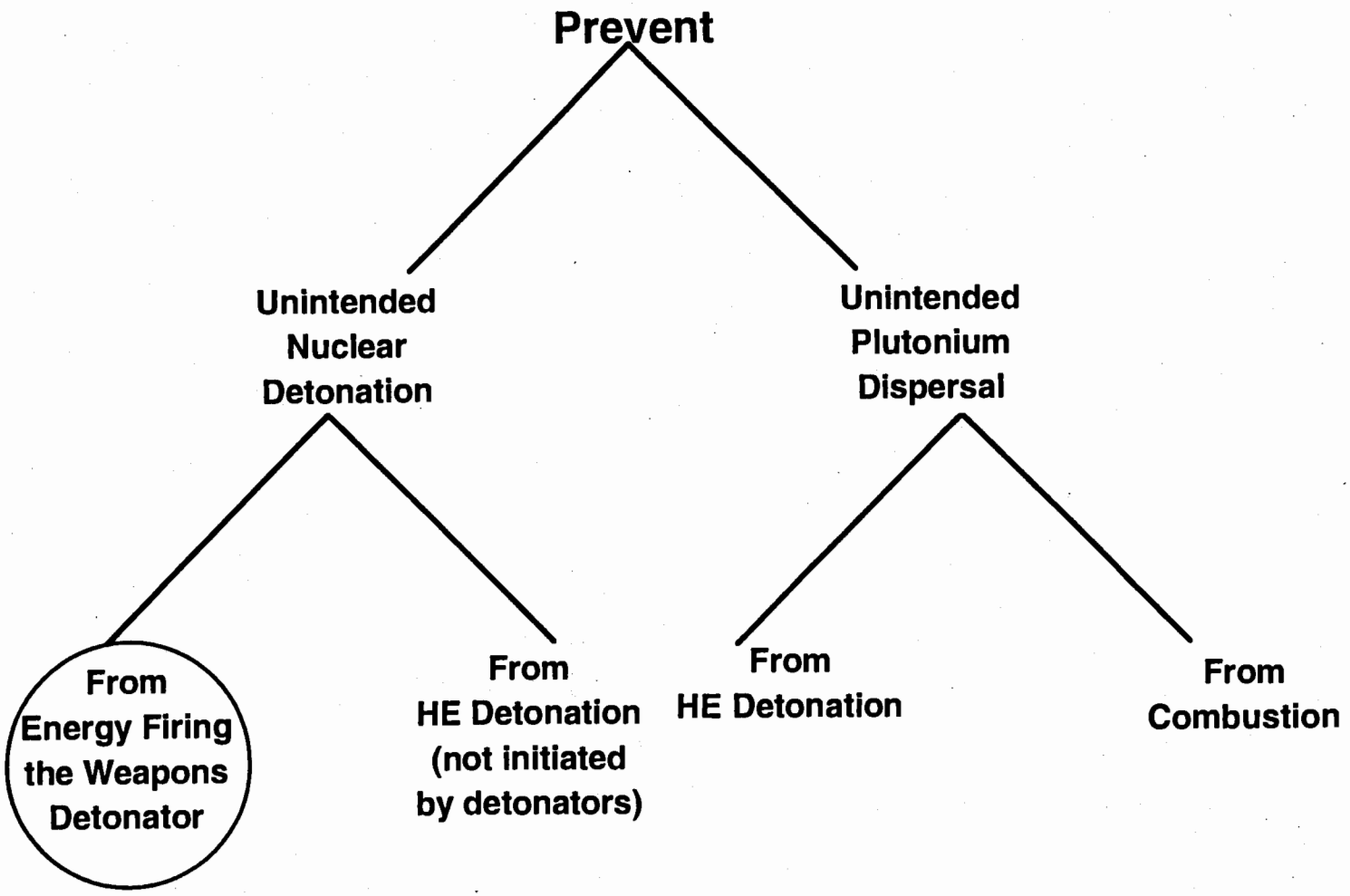
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Safety Goals for Abnormal Environments

- Assured, predictable, safe response of the warhead electrical system
- Maintain predictable, safe response until intended use
- Minimize safety critical components and dependence on knowing accident scenario

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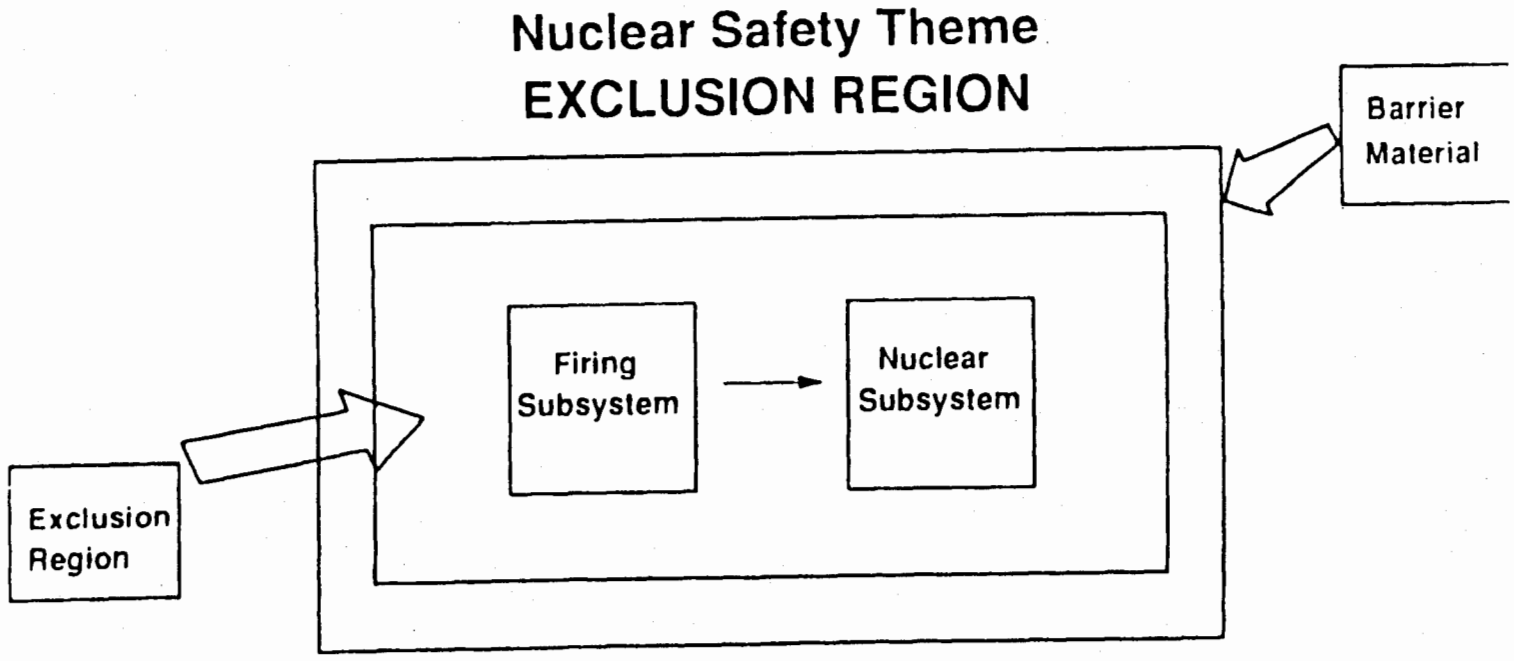
MORE SPECIFICALLY THE SAFETY GOALS ARE TO



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MODERN SAFETY DESIGN PHILOSOPHY

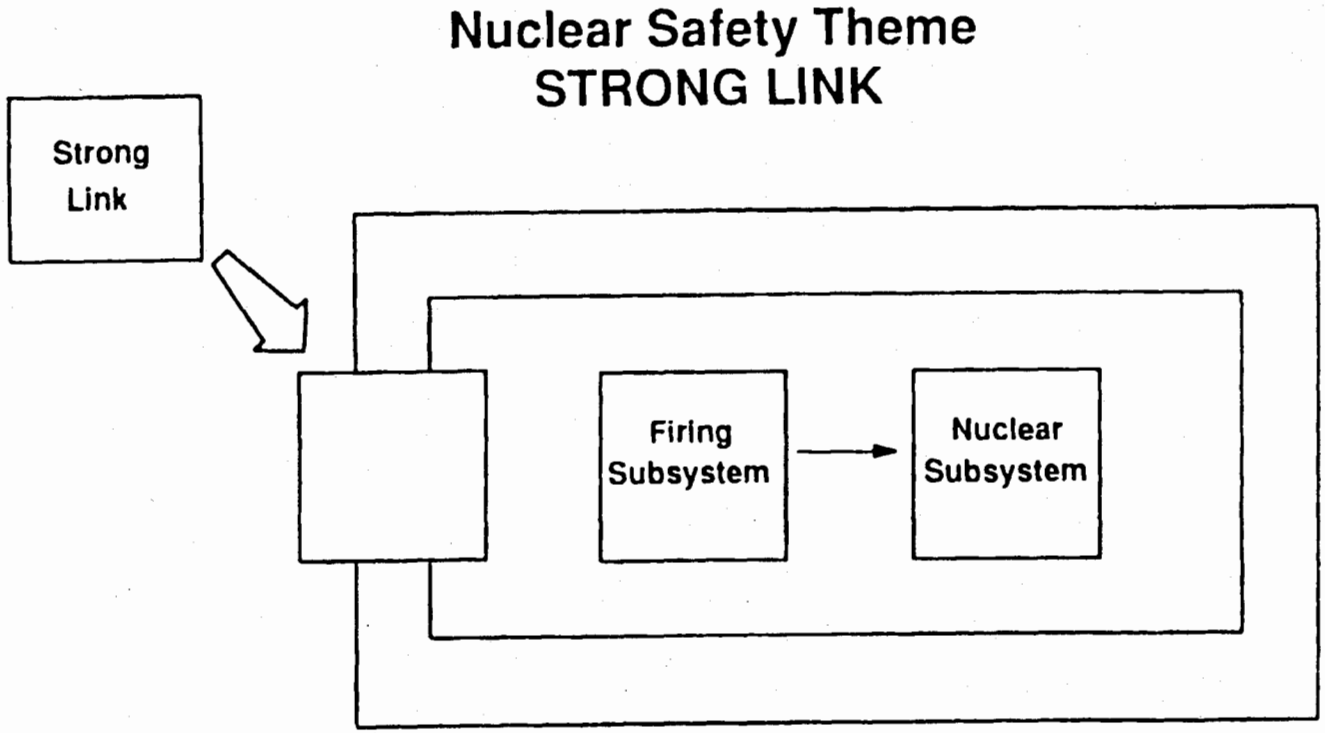
Co-locate detonation-essential components and protect them from abnormal environments by an exclusion region



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MODERN SAFETY DESIGN PHILOSOPHY (cont)

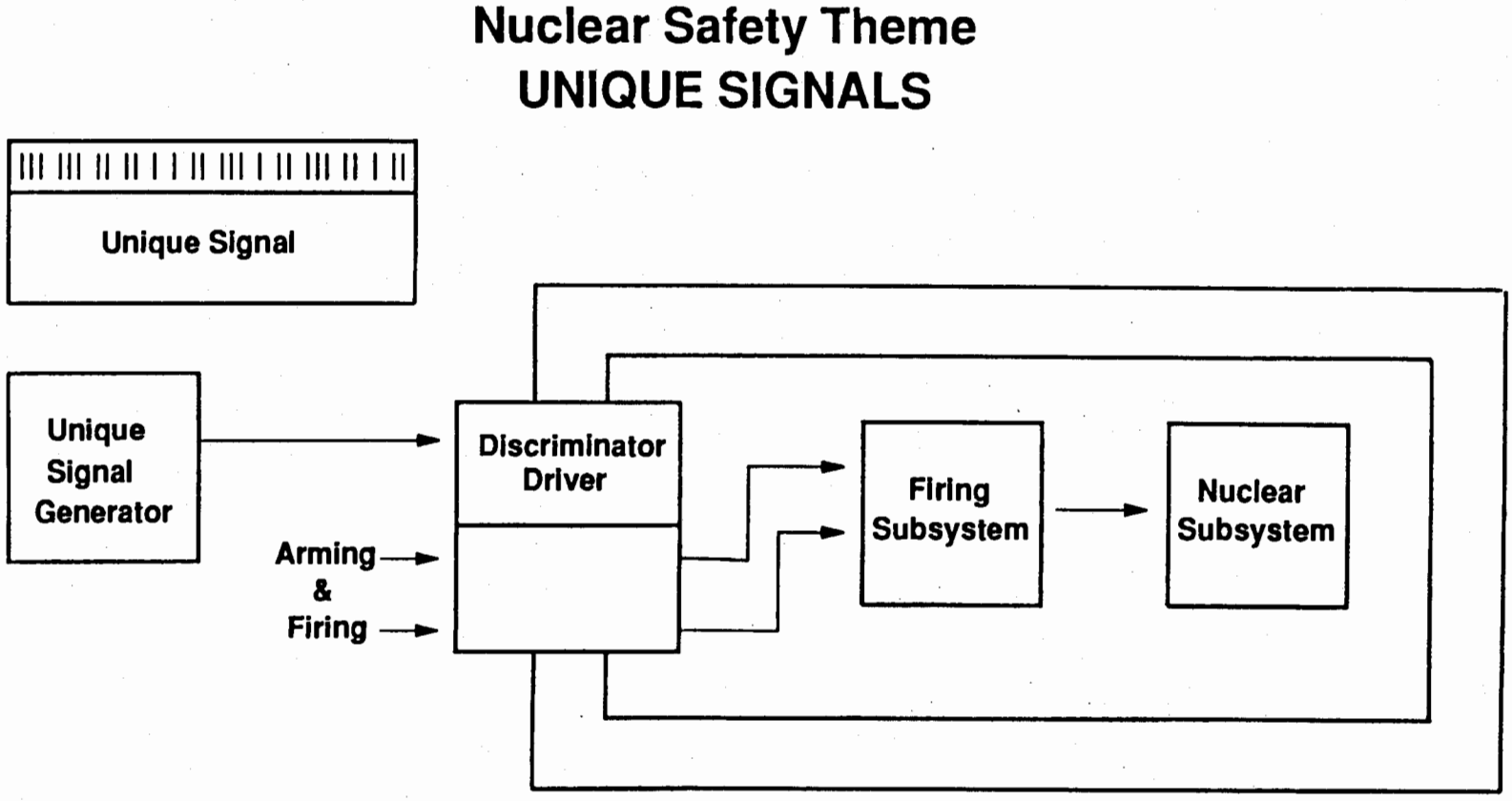
Allow energy/signals into the exclusion region only through a strong link



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MODERN SAFETY DESIGN PHILOSOPHY (cont)

Control the strong link(s) with a unique signal -- not duplicated elsewhere in the system

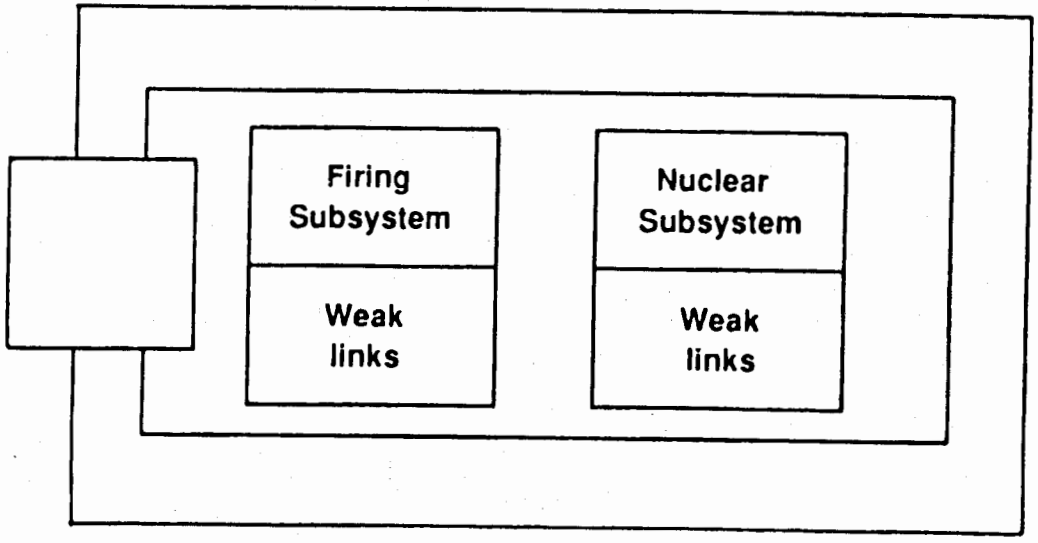


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MODERN SAFETY DESIGN PHILOSOPHY (cont)

Finally, to address credible but catastrophically severe environments, co-locate *weak link* detonation-essential components which will predictably become inoperable prior to the barrier or strong links losing their integrity.

Nuclear Safety Theme
WEAK LINKS



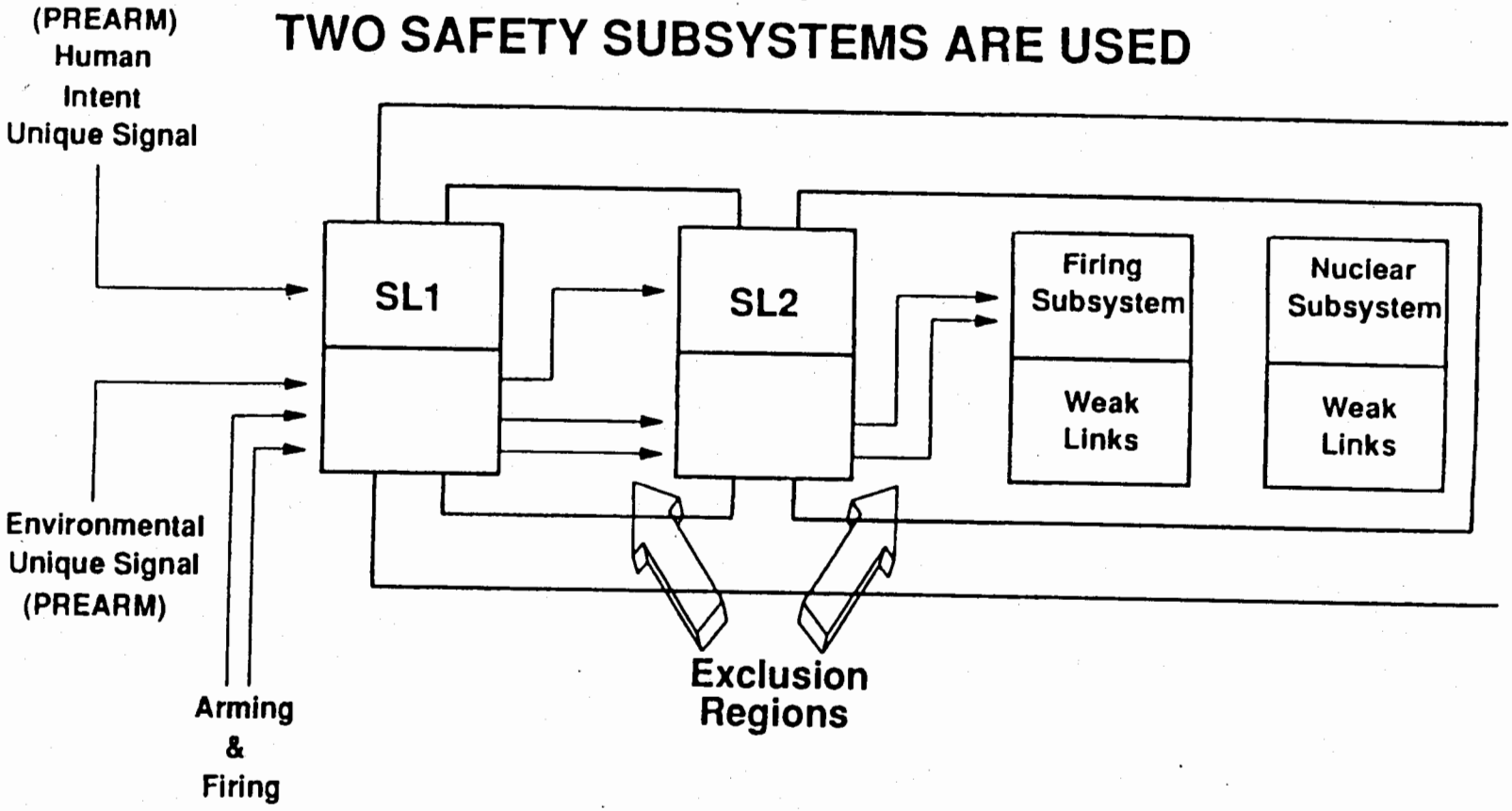
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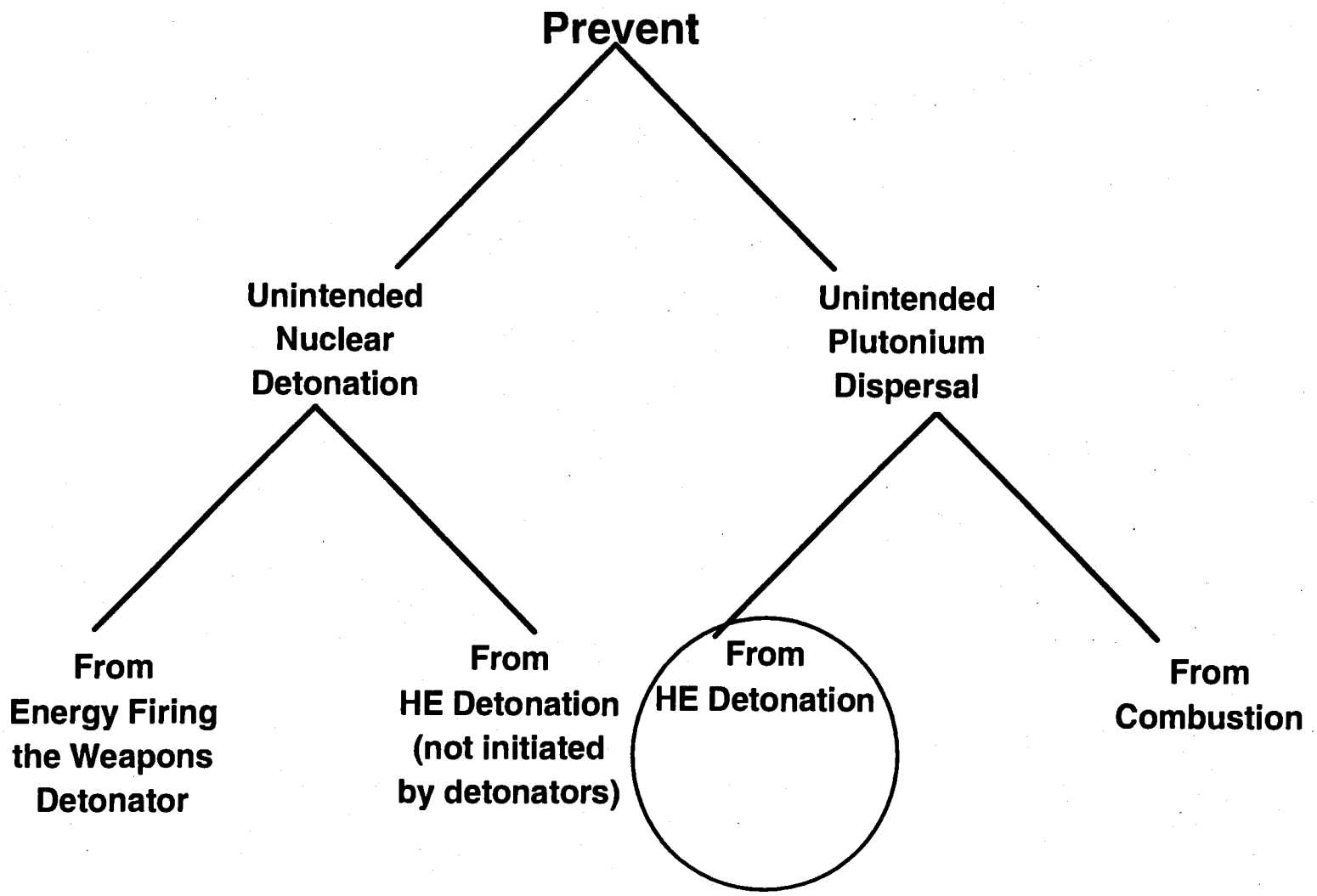
BECAUSE THE REQUIREMENT (LESS THAN ONE-IN-A-MILLION) IS QUITE STRINGENT

Nuclear Safety Theme

TWO SAFETY SUBSYSTEMS ARE USED



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"Failure to correct actual or perceived deficiencies in the areas of safety, security, and command and control can result in constraints being imposed on our nuclear forces that could greatly reduce their deterrent value."

April 24, 1975 White Paper distributed by ATSD (AE)

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THE NUCLEAR WEAPONS ACCESS CONTROL AND USE CONTROL PROGRAMS TRY TO:

- **Prevent unauthorized access to a nuclear weapon**
- **Prevent loss of custody of a nuclear weapon**
- **Prevent an intended (but unauthorized) nuclear explosion**
- **Prevent an intended (but unauthorized) dispersion of SNM**

AND...

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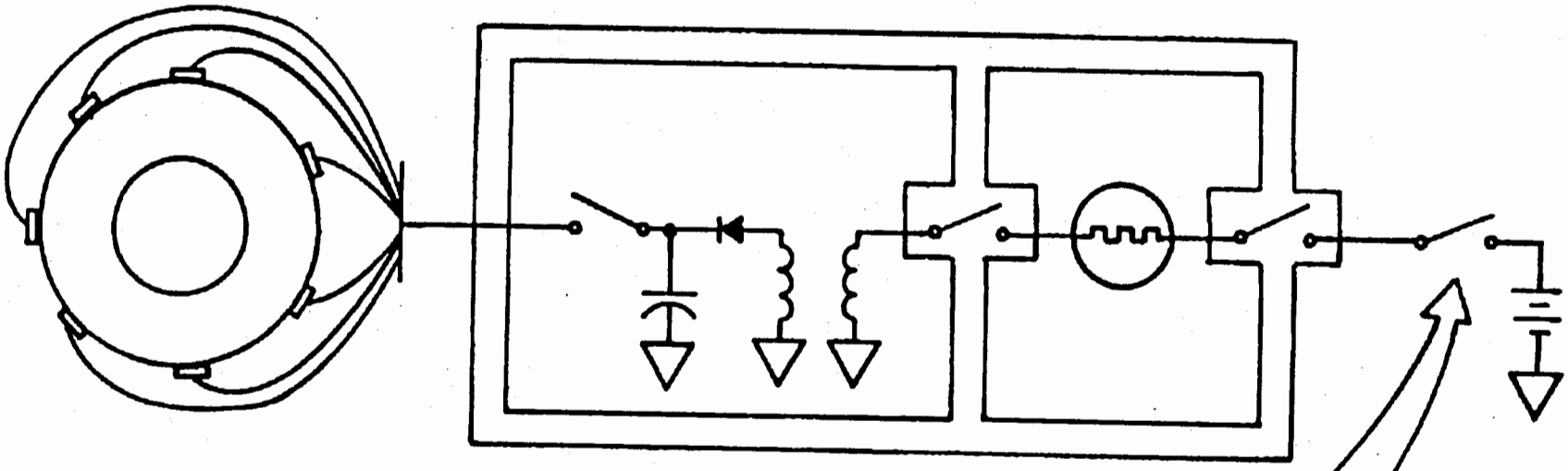
PAL (Permissive Action Link)

A code controlled switch which interrupts the warhead's arming circuit

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CONTROL - USE DENIAL

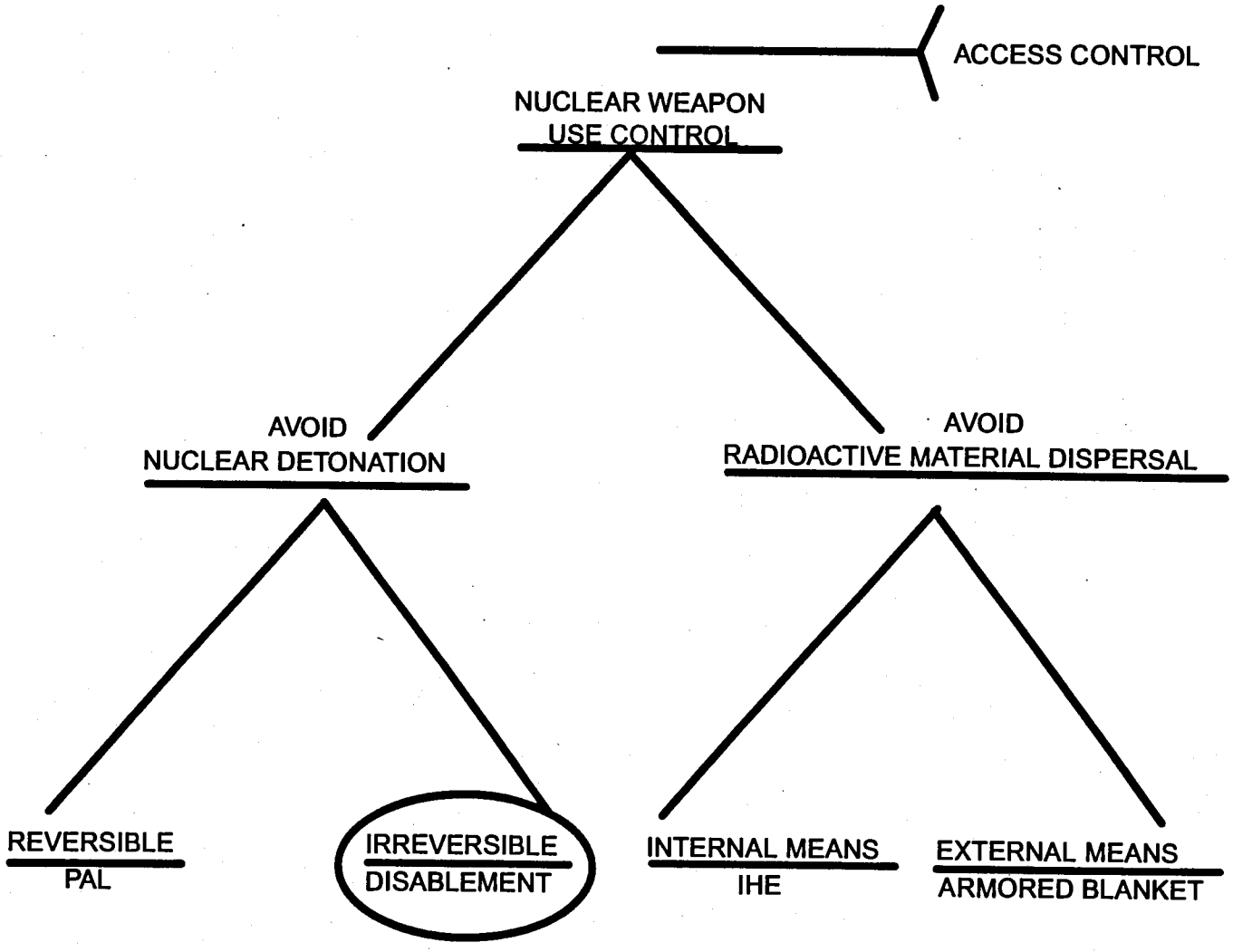


AUTHORIZED COMMAND STRUCTURE

PERMISSIVE ACTION LINK (PAL)

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DISABLEMENT

- When initiated, disables certain key nuclear detonation-essential components.

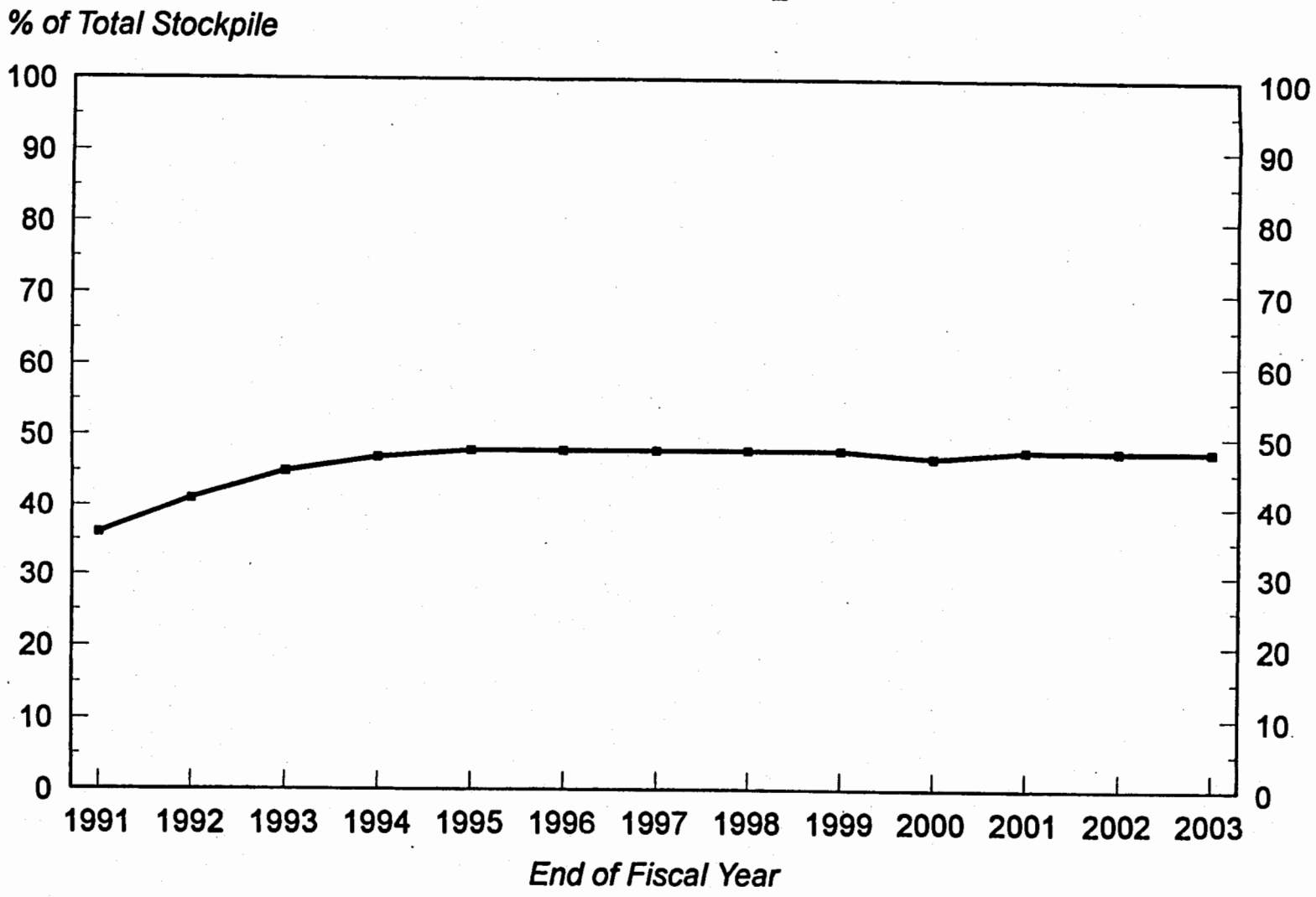
- Non-violent outside the weapon case.

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COMMAND DISABLEMENT

Source P&PD 93-2



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An Overview of the Evolution of Aircraft Monitor and Control (AMAC) Systems

- System 1 offered many improved features in safety and compatibility.
- The requirements for a Unique Signal Generator (USG) first appeared in July 1975 to enhance weapon safety in abnormal environments.
- The requirements for CAT D PAL first appeared in August 1975.
- The requirements for Command Disable (CD) first appeared in October 1981 to provide the ability to render a weapon useless from the cockpit.
- All aircraft nuclear weapon interfaces built to date have been analog.
- A system 2 AMAC specification exists that defines a digital interface for possible use in future nuclear weapons.

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An Overview of the Evolution of Aircraft Monitor and Control (AMAC) Systems

- The result of this effort resulted in the T249 AMAC for bomber and fighter aircraft usage.

- New bombs designed during the mid to late '50s were made compatible with the T249 rather than building a unique AMAC for a specific bomb.

- AMAC design specifications, defined jointly by the DOE and DoD, first appeared in December 1961.

- The requirements for Category (CAT) B Permissive Action Link (PAL) first appeared in June 1963 to enhance weapon security.

- Today's nuclear-capable aircraft, with few exceptions, have what is known as a System 1 AMAC interface.

- The System 1 specification first appeared in September 1963.

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Principle Elements of a Nuclear Weapon System

Physics Pkg.	Warhead Electrical System	Interface	Delivery System
Fissile Material	Fire Set	Carrying Package	Hand (ADM)
High Explosive	Power Source	Arming Logic	Truck (ADM)
Detonators	Neutron Source	Fuzes	Artillery
		RV Case	Aircraft/Bomb
		Parachute	Rockets
		Etc.	Missile
			Torpedo

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

SESSION II

- REVIEW OF WEAPONS PHYSICS
- THEORY OF NUCLEAR EXPLOSIONS

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The Gang of Four

$^{238}U_{92}$ % in nature - 99.27 When the $^{238}U_{92}$ is extracted, it is called depleted ^{238}U or TUBALLOY or D38 (from UK WWII effort - TUBE ALLOY). Will fission but not fissile Physically separated	^{239}Pu % in nature - essentially zero (mine in South Africa) Made in Reactor: N + ^{238}U = ^{239}Pu
^{235}U % in nature - 00.73 Concentrated to 93.5%. Called ORALLOY for Oak Ridge Alloy	^{240}Pu % in nature - essentially zero Made by reactor. If you leave the ^{239}Pu in "too long," it will absorb a N → ^{240}Pu. Spontaneously fissions (originally a problem for pre-ignition).

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CALCULATION OF ENERGY RELEASE

$$_{92}U^{235} + {}_{o}n^{1} \longrightarrow {}_{42}Mo^{95} + {}_{57}La^{139} + {}_{-1}e^{o} + 2\,{}_{o}n^{1}$$

235.0439	94.905837
1.0087	138.906400
	.003850
	2.017340
236.0526 amu ⟶	235.8334 amu

MASS DEFECT OF .219 amu

n = 1.00867 amu
p = 1.00728 amu
e = .00055 amu

$$(.219 \text{ amu})\ (931.4\ \tfrac{\text{MeV}}{\text{amu}}) \simeq 204 \text{ MeV}$$

THE EXAMPLE STARTED WITH

$$_{54}Xe^{139} \xrightarrow{3\,ß} {}_{57}La^{139} \quad \text{AND} \quad {}_{38}SR^{95} \xrightarrow{4\,ß} {}_{42}Mo^{95}$$

FISSION CHAIN

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THEORETICAL FISSION ENERGY

- THERE ARE $\frac{6.025X10^{23}}{235.0439}$ ATOMS PER GRAM OF $_{92}U^{235}$
- THEREFORE, 1 kg OF $_{92}U^{235}$ HAS $2.5634X10^{24}$ ATOMS
- HENCE, @ 180 MeV PER FISSION 1 kg OF $_{92}U^{235}$ WOULD PRODUCE
- $4.6141x10^{26}$ MeV IF EACH ATOM WERE FISSIONED.
- CONVERTING TO KILOTONS
- $(4.6141X10^{26}\ \text{MeV})\ (3.824X10^{-26}\ \frac{kT}{MeV}) \simeq 18\ kT$

T

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FACTORS AFFECTING CRITICAL MASS

- GEOMETRY
- AMOUNT OF MATERIAL
- TYPE OF MATERIAL
- PURITY OF MATERIAL
- SURROUNDING MATERIAL
- DENSITY

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WEAPONS MATERIALS

Plutonium 239 = Pu ^{239} = P $_{94}^{239}$ = Pu

Made by placing natural uranium as the target in a reactor. Weapons grade Pu = having less than 6% Pu ^{240}.

Oralloy = Oy = Uranium that has been enriched to 93 .X% U_{92}^{235}

Tuballoy -- Tu -- natural uranium but also includes depleted uranium (i.e. U^{238})

Tritium = H_1^3 = T^3 = T

DoD 4121

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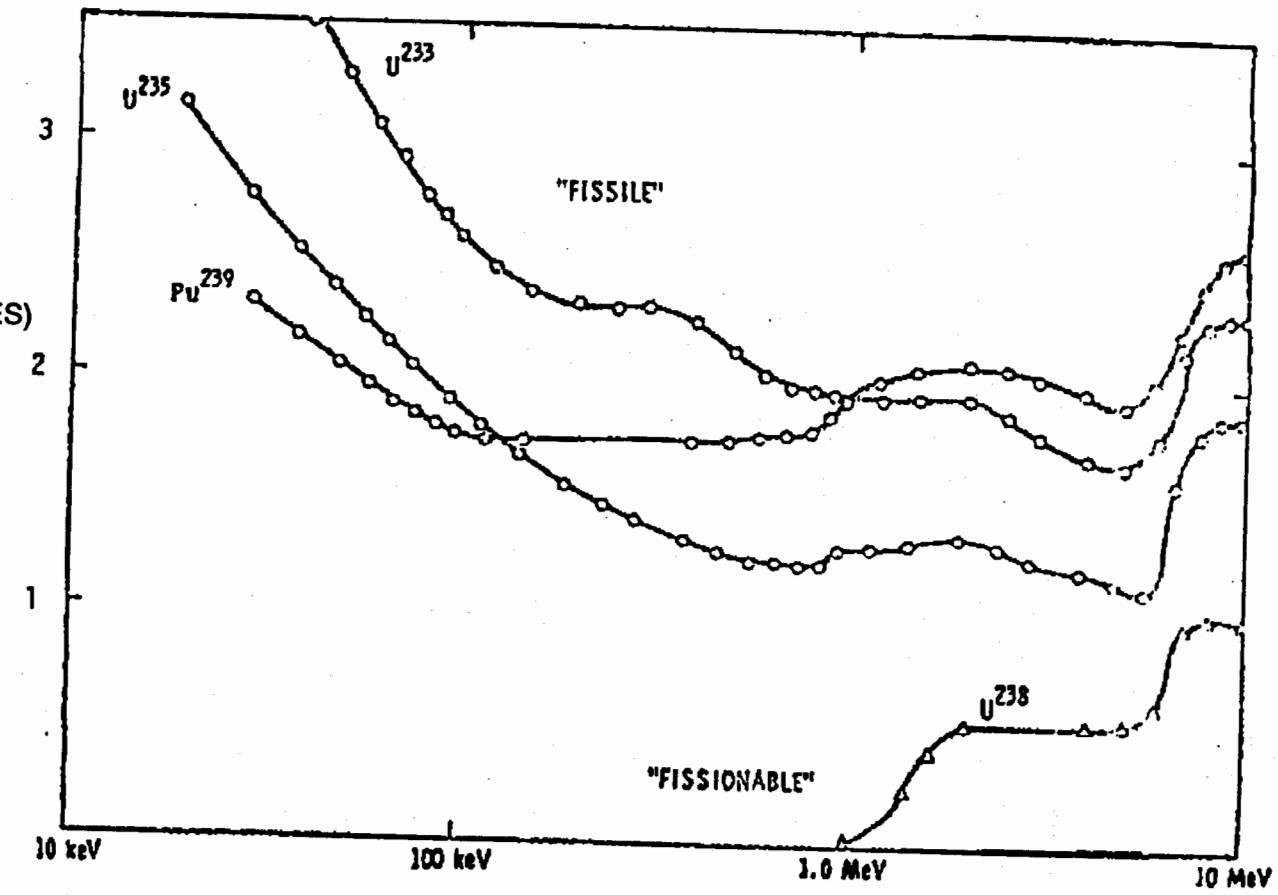
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Alloy Metal / Property	~ Pu	δ -Pu
Alloy Material	Alloy	1 ±0.2 wt % Ga
Maximum Stable Temp (^{o}C)	117	525
Density (g/cm^{3})	19.6	15.8
Working Characteristic Similar to	Brittle, Cast Iron	Annealed Copper
Tensile Strength (GPa)[3]	0.62	0.1
Weldability	Not	Easily
Coefficient of Linear Expansion @ 25°C (10^{-6} cm/ cm- ^{o}C)	54	6

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FISSION CROSS SECTIONS



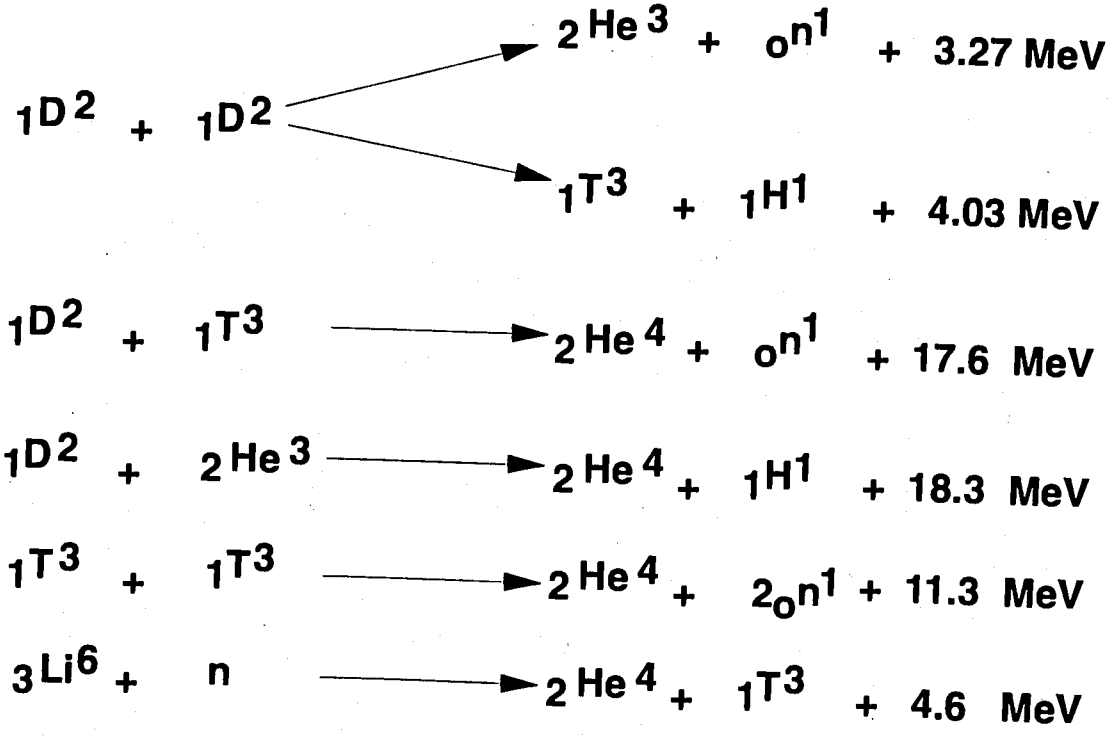
INCIDENT NEUTRON ENERGY

NOTE: The thermal neutron energy is not on the chart

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Potential Fusion Reaction



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TEMPERATURE EXPRESSED IN kT (ENERGY)

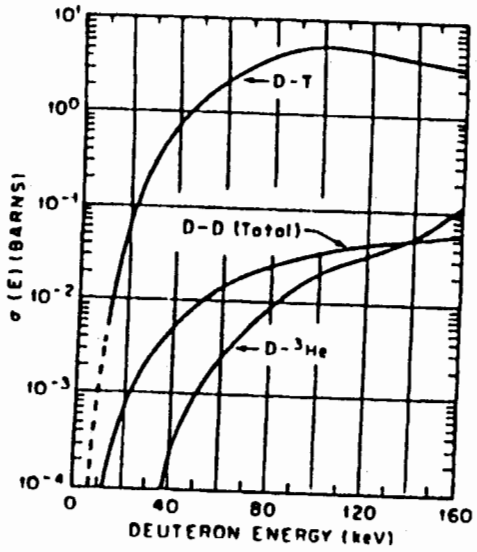
where K is Boltzmann Constant { 1.38×10^{-16} erg/ °K ; 8.62×10^{-8} keV/ °K

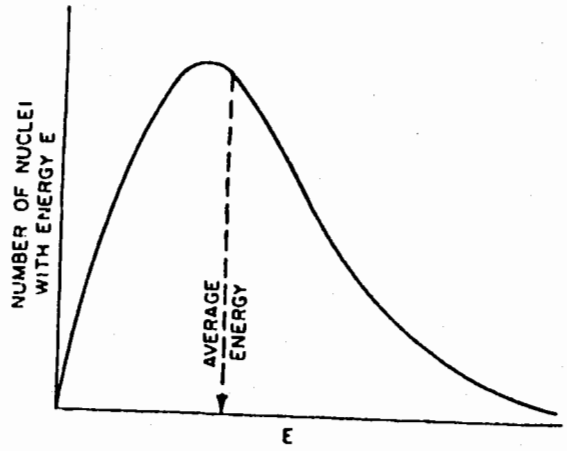
$T \text{ (in keV)} = 8.62 \times 10^{-8} \; T \text{ (in } ^\circ\text{Kelvin)}$

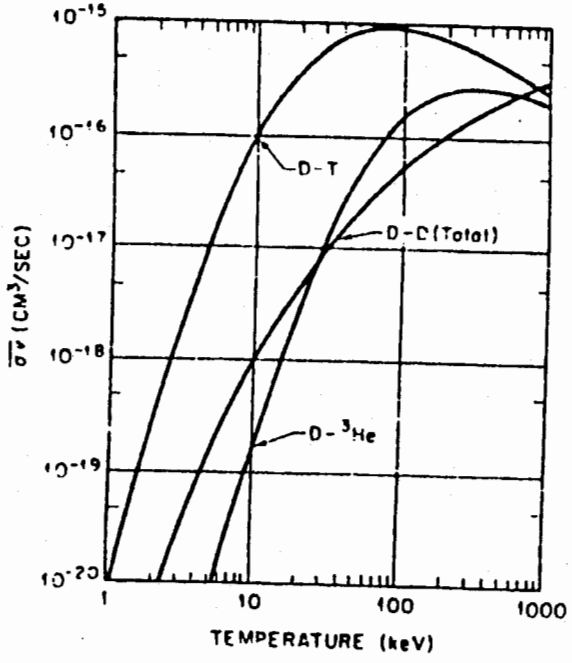
Temperature of 1 keV = 1.16×10^{7} degrees Kelvin

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Thermal Nuclear Plasma

AT FUSION TEMPERATURES, WE HAVE A PLASMA OF IONS (NUCLEI AND ELECTRONS).

$$\text{ENERGY} = aT_{(\text{ion})} + bT_{(\text{electron})} + cT^4_{(\text{radiation})}$$

IF PLASMA IS IN THERMODYNAMIC EQUILIBRIUM THE THREE TEMPERATURES ARE EQUAL ➡ AT HIGH TEMPERATURES, RADIATION WILL DOMINATE.

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REFERENCES

AN INTRODUCTION TO NUCLEAR WEAPONS; WASH 1037 REVISED;
SRD (N) SIGMA 1 etc.; GLASSTONE AND REDMAN.

SOURCE BOOK ON ATOMIC ENERGY; GLASSTONE; UNC 3rd EDITION

BASIC NUCLEAR PHYSICS; INTERSERVICE NUCLEAR WEAPONS SCHOOL

DNA PUBLICATIONS — TECHNOLOGY ANALYSIS REPORT

SANDIA, LLL, LANL TECHNOLOGY REPORTS

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

SESSION III

- NUCLEAR EFFECTS

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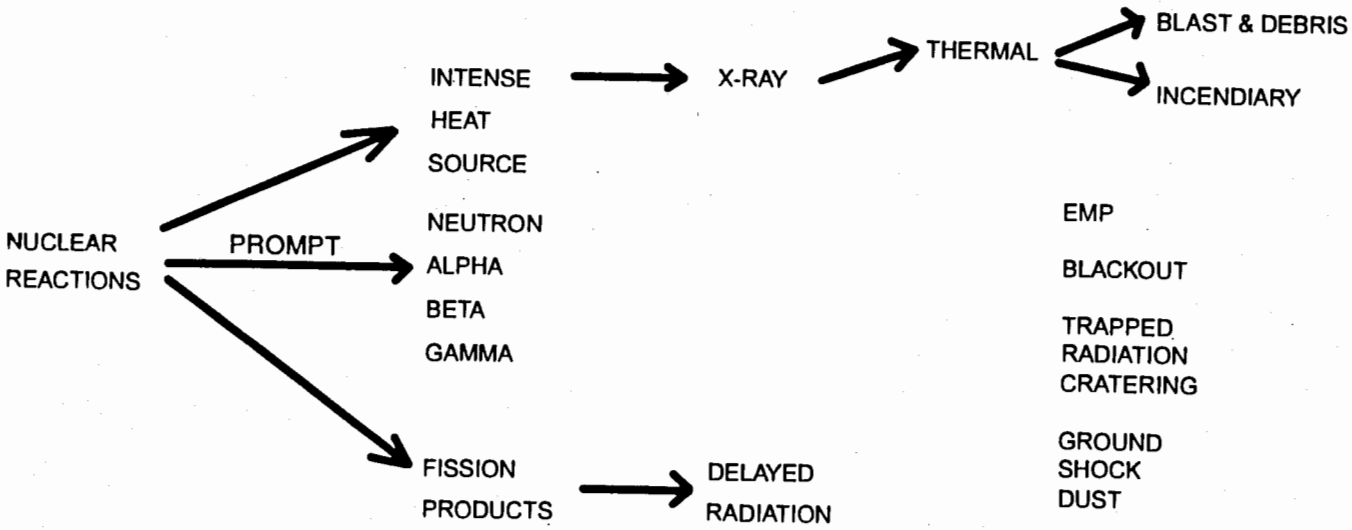
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CONVENTIONAL WEAPON

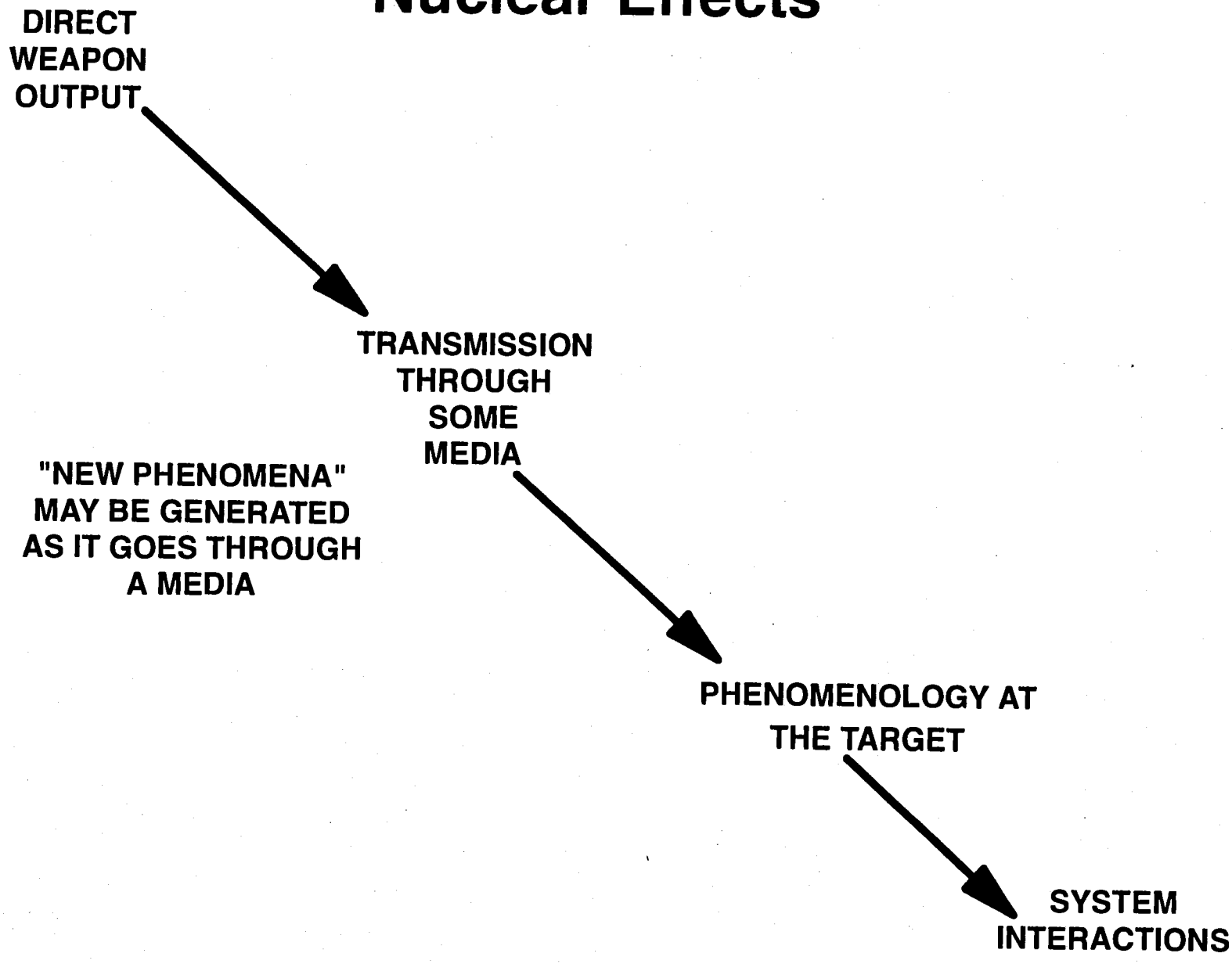


NUCLEAR WEAPON



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Nuclear Effects

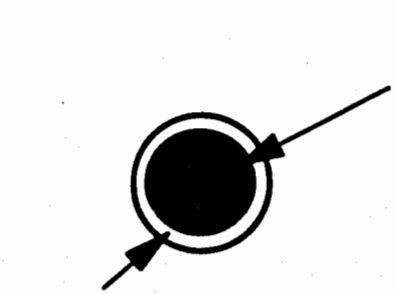


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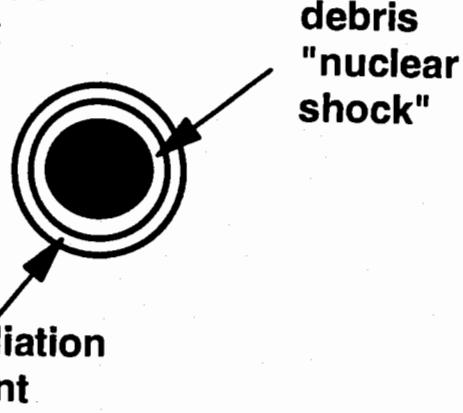
3. THE MEAN FREEPATH OF "X-RAYS" IS .3 cm AT SEALEVEL. THE SURROUNDING LAYER OF AIR IS SUPERHEATED. INITIAL X-RAY FIREBALL



4. THIS ABSORPTION AND RERADIATING PROCESS RESULTS IN A RAPIDLY EXPANDING RADIATION FIREBALL. RADIATION GROWTH PHASE.



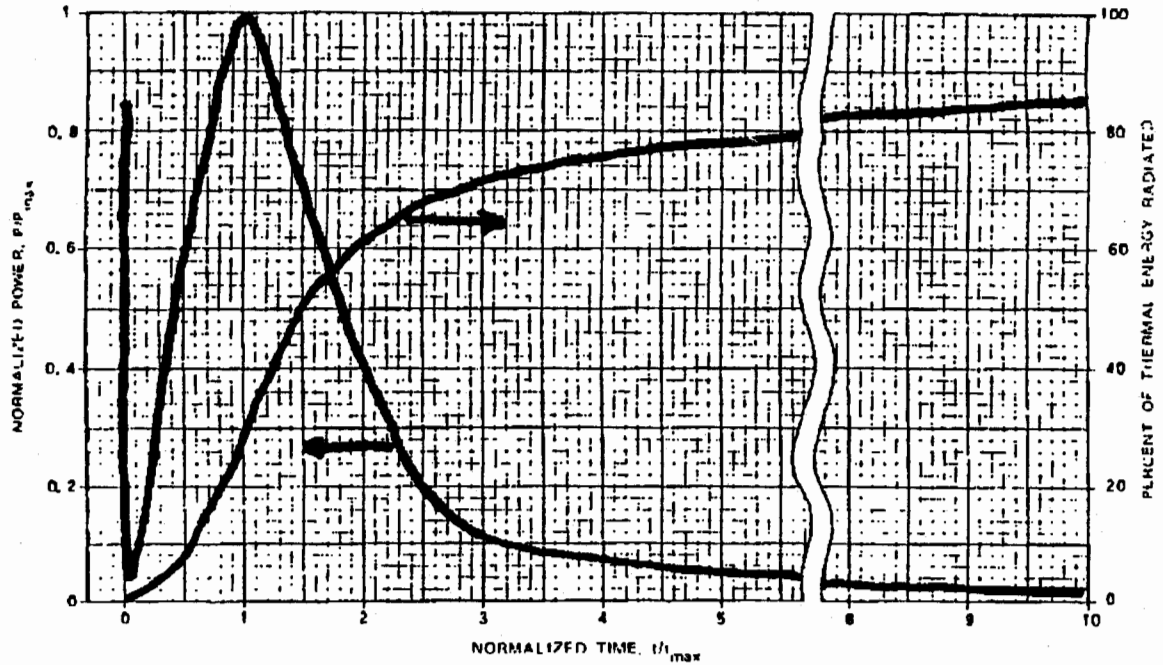
5. THE WEAPON DEBRIS SNOWPLOWS AIR AND A "NUCLEAR SHOCK" IS FORMED. RADIATION FIREBALL CONTINUES TO GROW, BUT GROWTH SLOWS BECAUSE COOLING REDUCES MFP.



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Power-Time and Energy-Time Curves for a 200 Kiloton Burst at 5000 ft



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AWAY FROM SOURCE AIRBLAST

SCALABLE PHENOMENA — SACH'S SCALING $\left[\frac{D_1}{D_0}\right] = \left[\frac{W_1}{W_0}\right]^{1/3}$

BASIS IS COMPLETE DATA FOR 1 CASE EX: 1 KT STANDARD

FOR ALTITUDES OTHER THAN SEA LEVEL $\left[\frac{D_1}{D_0}\right] = \left[\frac{W_1}{W_0}\right]^{1/3}\left[\frac{P_0}{P}\right]^{1/3}$

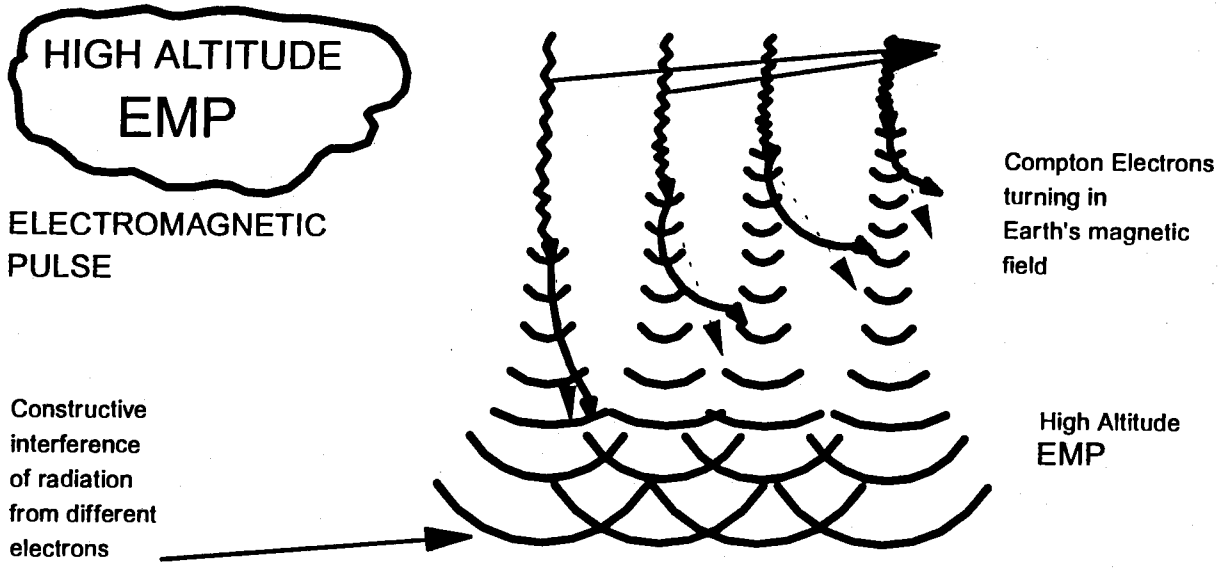
OTHER IMPORTANT ASPECTS:

- MACHSTEM AND TRIPLE POINT PATH
- OPTIMAL HOB FOR MAXIMIZING OVERPRESSURE
- PRECURSOR

WILL BE COVERED LATER AND IN THE EFFECTS MOVIE

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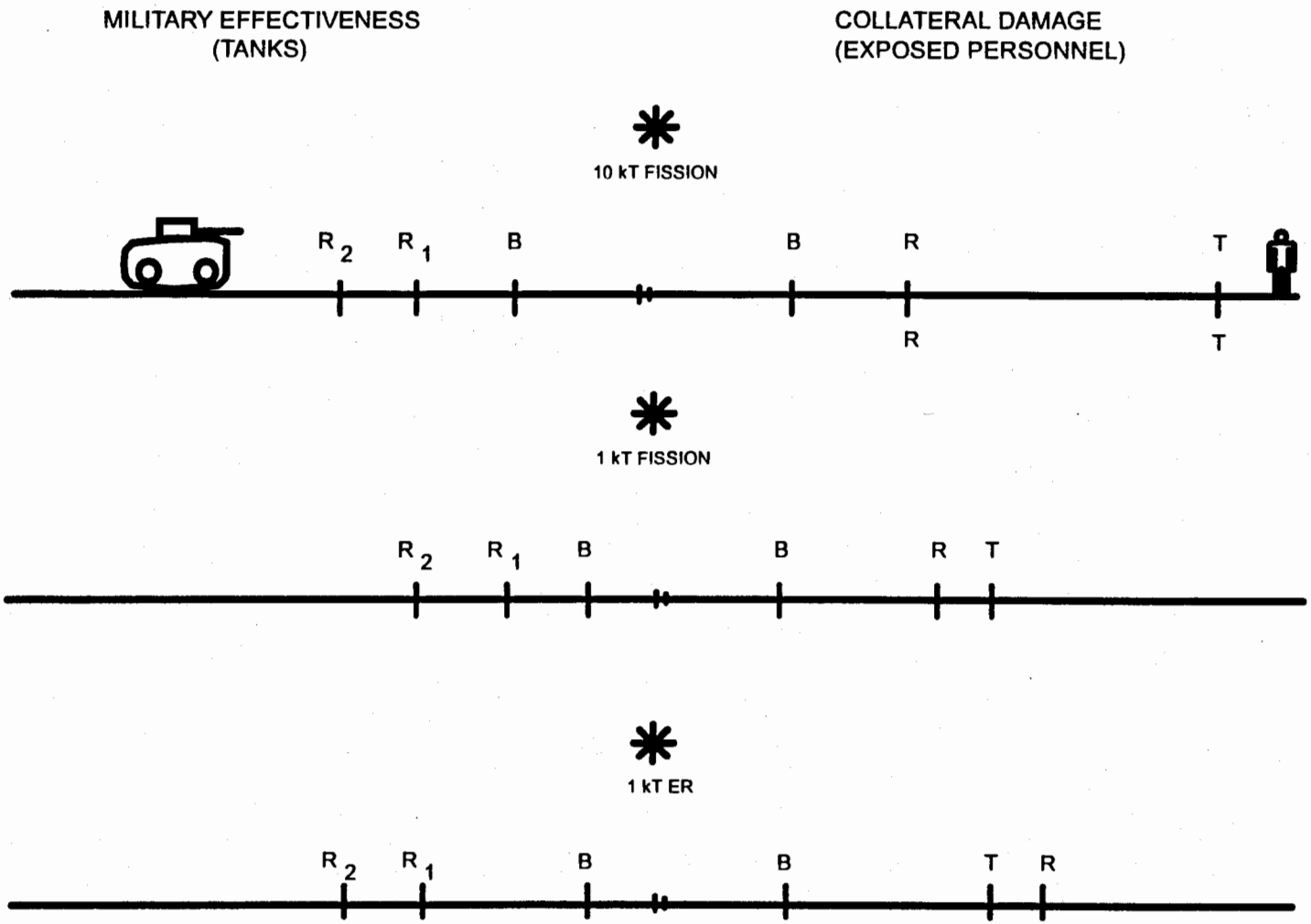


KEY Points

1. Each γ gives a downward traveling compton electron.
2. The electrons are turned by the earth's magnetic field.
3. The realistic electrons radiate energy downward.
4. The γ's and EMP radiation travel at the same speed.
   This leads to constructive interference of radiation from all electrons.

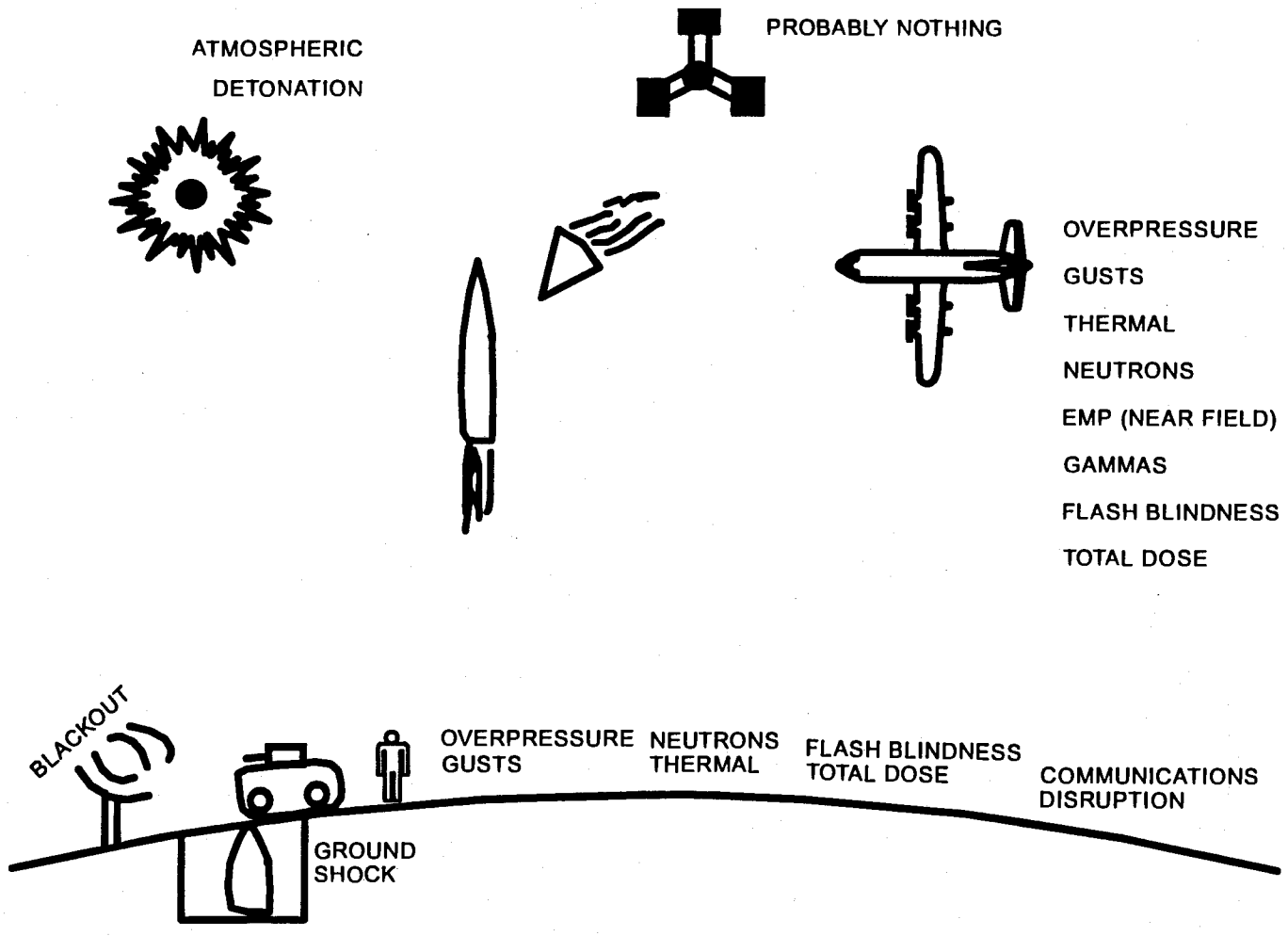
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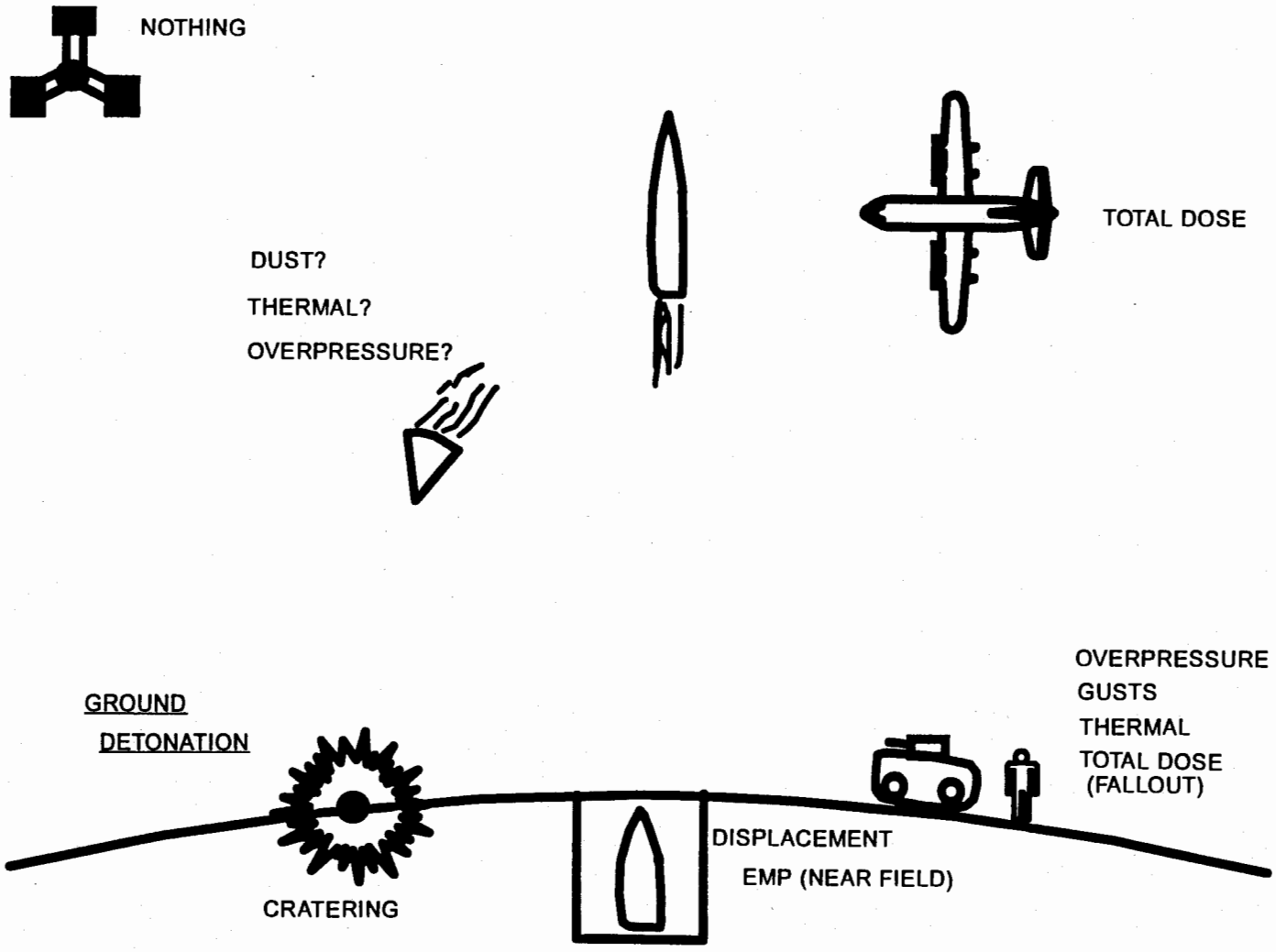


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Nuclear Targeting

- Through intelligence data, the targets have a vulnerability number associated with it that allows the DoD to assign a weapon.
- Vulnerability Number (VN)

  XXP<u>A</u> XXQ<u>A</u>

  First 2 digits are related to the amount of pressure:
  - P = over pressure (smash)
  - Q = dynamic pressure (winds)
  - A = adjustment for yield (tables geared to 20 KT)
- A typical VN:

  Airfield = 12 P0 ~ 10 psi

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PURE EXPLOSIVE COMPOUNDS.

Material[a]	Chemical name	Other designations	Color
*BTF	Benzotris-[1,2,5] oxadiazole-[4,4,7]-trioxide	Benzotrifuroxan, hexanitrosobenzene	Buff
*DATB	1,3-Diamino-2,4,6-trinitrobenzene		Yellow
*DIPAM	3,3-Diamino-2,2',4,4',6,6'-hexanitrobiphenyl	Hexanitrodiphenyl-amine hexite, dipicrylamine	—
*DNPA	2,2-Dinitropropyl acrylate		Off-white
*EDNP	Ethyl-4,4-dinitropentanoate		Yellow
*FEFO	Bis(2-fluoro-2,2-dinitroethyl)-formal		Straw
**HMX	1,3,5,7-Tetranitro-1,3,5,7-tetraazacyclooctane	Cyclotetramethylene tetranitramine, octogen	White
*HNAB	2,2',4,4',6,6'-Hexanitroazo-benzene		Orange
*HNS	2,2',4,4',6,6'-Hexanitrostilbene		Yellow
**NC (12% N)[b]	Partially nitrated cellulose	Nitrocellulose (lacquer grade), cellulose trinitrate, piroksilin	White
*NC (13,35% N, min)[b]	Partially nitrated cellulose	Nitrocellulose, guncotton	White
*NG	1,2,3-Propanetriol trinitrate	Nitroglycerin	Clear
*NM	Nitromethane		Clear
*NQ	Nitroguanidine	Aminomethaneamidine	White
**PETN	Pentaerythritol tetranitrate	Penthrite, TEN	White
**RDX	1,3,5-Trinitro-1,3,5-triaza-cyclohexane, hexahydro-1,3,5-trinitro-s-triazine	Cyclotrimethylene trinitramine, hexogen cyclonite,Gh	White
*TACOT	Tetranitro-1,2,5,6-tetraazadi-benzocyclooctatetrene	Tetranitrodibenzo-1,3a,4,6a-tetraazapentalene	Red-orange
**TATB	1,3,5-Triamino-2,4,6-trinitro benzene		Bright yellow
**Tetryl	2,4,6-Trinitrophenylmethyl-nitramine		Yellow
**TNM	Tetranitromethane		Clear
**TNT	2,4,6-Trinitrotoluene	Trotyl,T,tol	buff to brown

**Denotes it has been used in nuclear weapons

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Cast explosives: names and formulations.

Explosive[a]	Formulation (wt%)[b] TNT	RDX	Other ingredients	
Baratol	24		$Ba(NO_3)_2$	76
Boracitol	40		Boric Acid	60
*Comp B, Grade A[c]	36	63	Wax	1
Comp B-3	40	60		
*Cyclotol[d]	25	75		
H-6	30	45	Wax	5
			Al	20
			$CaCl_2$	0.5
*Octol	25		HMX	75
*Pentolite[d]	50		PETN	50
Tritonal	80		Al	20

[a]Properties of materials marked with asterisks are summarized in data sheets (Section IV).
[b]The weight percent values given in the table are nominal and subject to some variation.
[c]Comp B, Grade A is formulated as a 60/40 RDX/TNT mixture, but high-quality castings usually are higher in RDX content due to the removal of a TNT-rich section at the top of the casting.
[d]There are several cyclotols and pentolites. The most common cyclotol is RDX/TNT 75/25. The most common pentolite is PETN/TNT 50/50.

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Plastic-bonded explosives: Names and formulations.

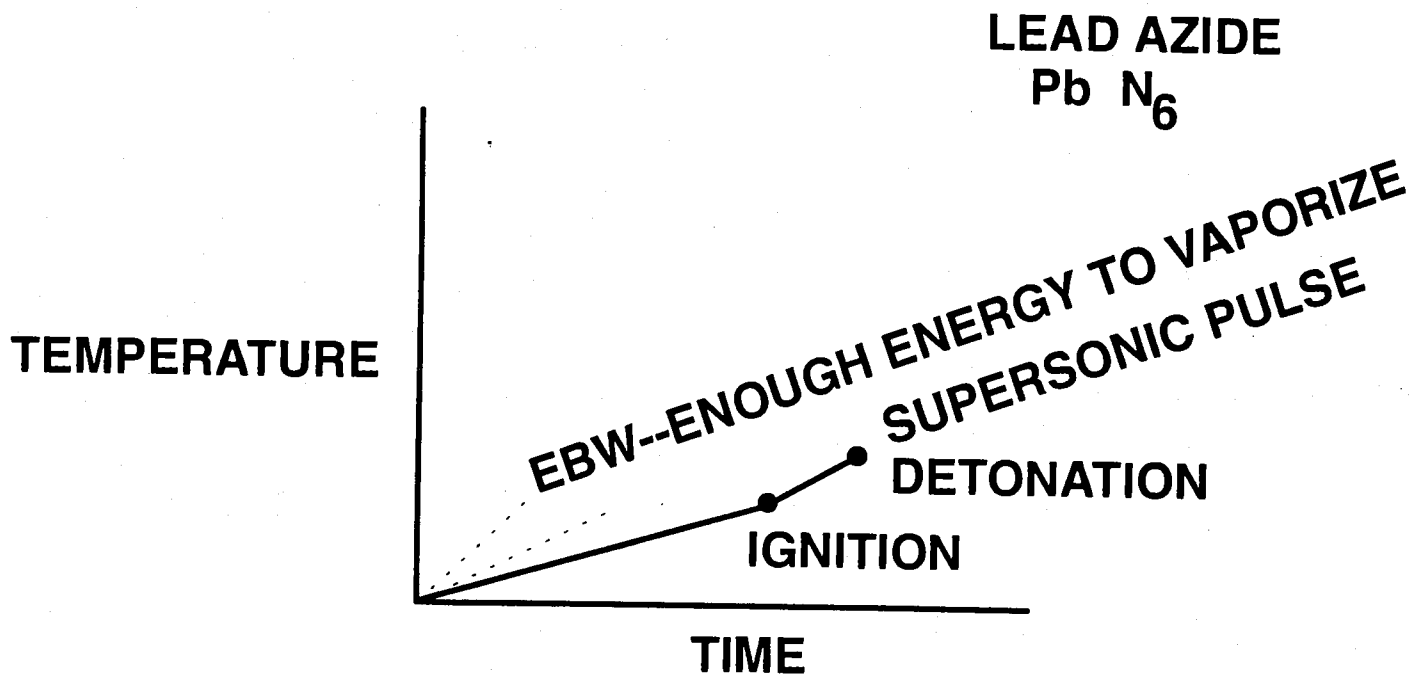
Explosive[a]	Other ingredients	Formulation Ingredient	Formulation wt%	Color
*LX-04-1	PBHV-85/15	HMX	85	Yellow
		Viton A	15	
*LX-07-2	RX-04-BA	HMX	90	Orange
		Viton A	10	
*LX-09-0	RX-09-CB	HMX	93	Purple
		pDNPA	4.6	
		FEFO	2.4	
LX-09-1		HMX	93.3	Purple
		pDNPA	4.4	
		FEFO	2.3	
*LX-10-0	RX-04-DE	HMX	95	Blue-green spots on white
		Viton A	5	
LX-10-1		HMX	94.5	Blue-green spots on white
		Viton A	4.5	
*LX-11-0	RX-04-PI	HMX	80	White
		Viton A	20	
*LX-14-0		HMX	95.5	Violet spots on white
		Estane 5702-FI	4.5	
*PBX-9007	PBX-9007 Type B	RDX	90	White or mottled gray[b]
		Polystyrene	9.1	
		Di(2-ethyl-hexyl)-phthalate	0.5	

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Plastic-bonded explosives: Names and formulations. (cont.)

		Formulation		
		Rosin	0.4	
*PBX-9010		RDX	90	White
		Kel-F	10	
*PBX-9011	X-0008	HMX	90	Off-white
		Estane 5740-X2		
*PBX-9205		RDX	92	White
		Polystyrene	6	
		Di(2-ethyl-hexyl)-phthalate	2	
*PBX-9404	PBX-9404-03	HMX	94	White or blue
		NC (12.0% N)	3	
		Tris (B-chloro-ehtyl)-phosphate	3	
*PBX-9407		RDX	94	White or black[b]
		Exon 461	6	
*PBX-9501		HMX	95	White
		Estane	2.5	
		BDNPA	1.25	
		BDNPF	1.25	
PBX-9502		TATB	.05 Kel F	
LX-17		TATB	.075 Kel F	

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EBW (EXPLODING BRIDGEWIRE) EVOLVED

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REFERENCES

- AN INTRODUCTION TO NUCLEAR WEAPONS; WASH 1037 REVISED; GLASSTONE, JUNE 1972

- PROPERTIES OF CHEMICAL EXPLOSIVES AND EXPLOSIVE SIMULANTS; LLL JULY 31, 1974, DOBRATZ UCRL - 51319, REV 1

- SENSITIVITY OF INITIATION-SYSTEM DETONATORS: REVIEW OF CURRENT AND ADVANCED TECHNOLOGIES; R. E. SETCHELL; SAND91-1590

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REFERENCES

- AN INTRODUCTION TO NUCLEAR WEAPONS; WASH 1037 REVISED, GLASSTONE, JUNE 1972

- SOURCE BOOK ON ATOMIC ENERGY; GLASSTONE, 3rd EDITION

- NUCLEAR TEST SUMMARY TRINITY — HARDTACK DASA 1220; RS3141/10349

- VARIOUS WEAPON DEVELOPMENT REPORTS

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

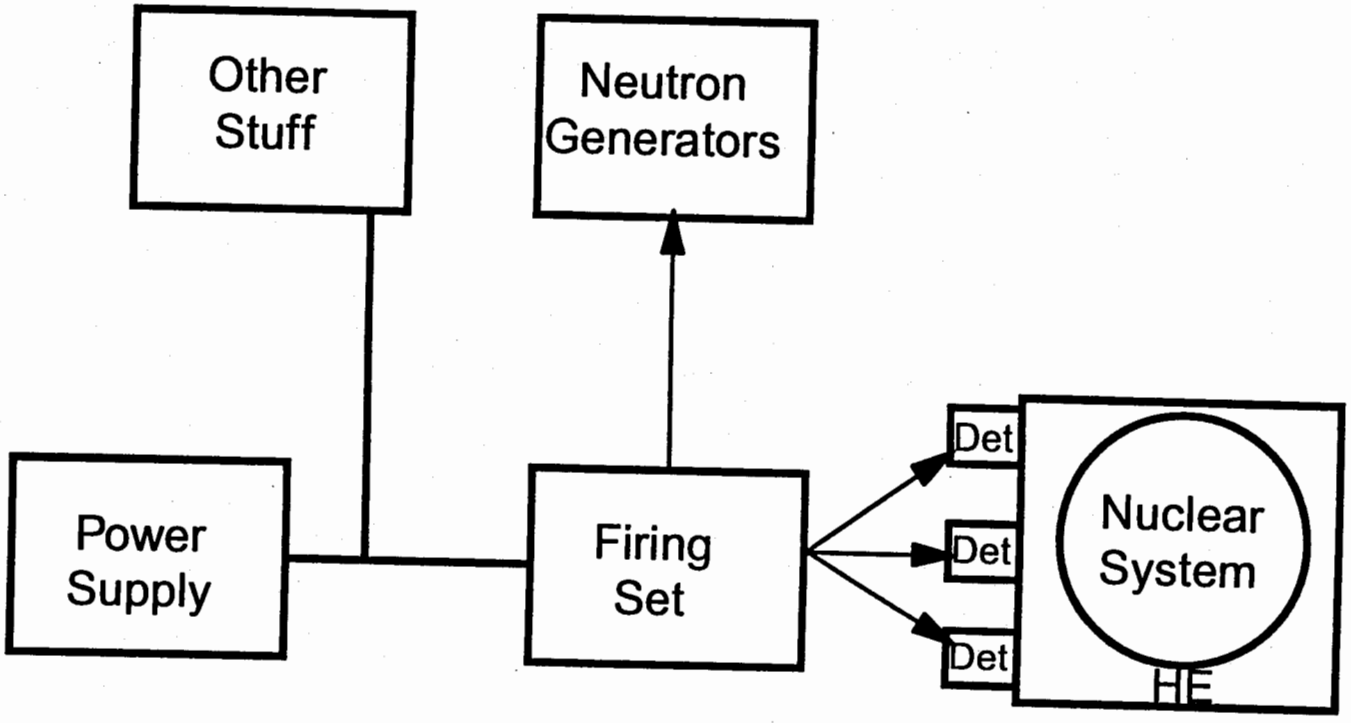
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SESSION XI

ARMING, FIRING, AND INITIATION

- POWER SUPPLIES
- FIRING SETS
- NEUTRON SOURCES

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Bomb--Yes
WH--Maybe

Nuclear Weapon

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Nomenclature

Reserve Battery - Any battery which will not deliver current until activated, e.g., by adding electrolyte or melting electrolyte

Thermal Battery - A reserve battery activated by raising the temperature to melt the electrolyte, which is a salt mixture - used extensively in nuclear weapons

Depolarizer Pad - The active cathode material which is reduced electrochemically during battery discharge

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Nuclear Weapon Batteries

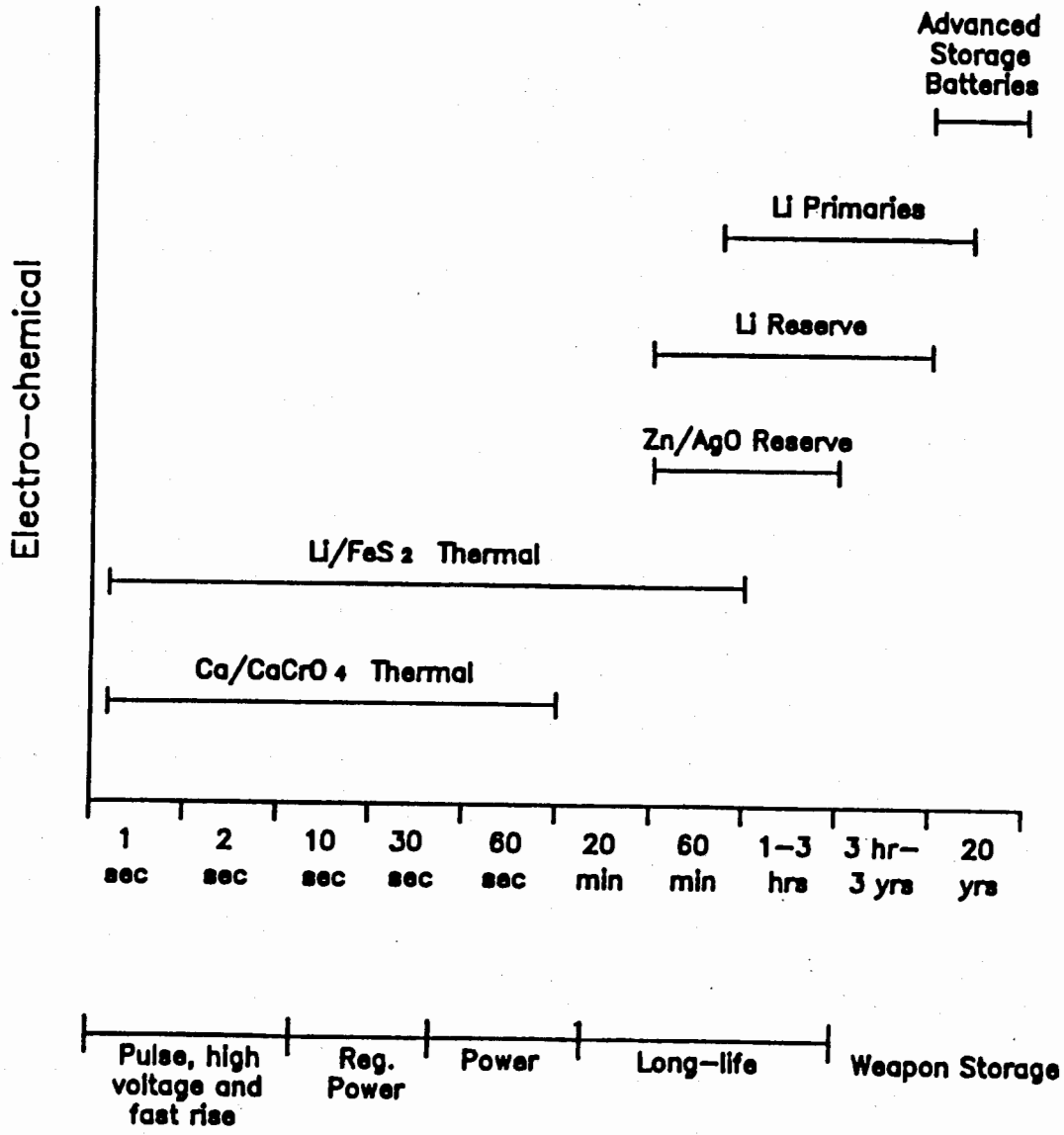
Little Boy	NT—6	Lead Acid	1945
Fat Man	ER—12	Lead Acid	
MK 4, 5, 6, 7	MC193	Nickel—Cadmium	1953
MK 12	MC271	Silver—Zinc	
MK 15	MC473	Thermal Ca—$CaCrO_4$	1955
Multiple	Multiple	Thermal Li—FeS_2	1970's
All New Designs		Thermal Li—FeS_2	Present

NOTE: JTA's, controllers, and support equipment may utilize designs other than thermal batteries

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Battery Technologies



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Reactions

$Ca/CaCrO_4$

- **Electrochemical:**

Anode – $Ca \xrightarrow{Li^+} CaLi_2 \rightarrow Ca^{2+}$(double salt)$\downarrow + 2e^-$

Cathode – $CrO_4^{2-} + 3e^- \rightarrow$(soluble intermediates) $\xrightarrow{Li^+}$ $Ca_6Cr_4O_xSiCl_2$, $Li_xCa_yCrO_4$, $Li_xCr_yO_z$, CaO

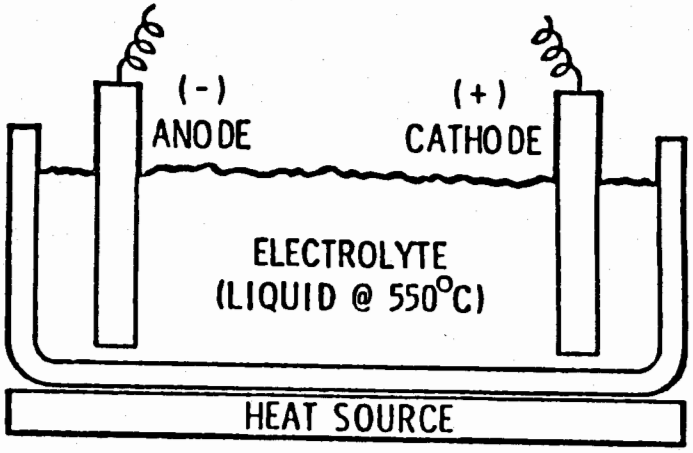
- **Identifiable Side Reactions:**

$4Ca + SiO_2 \rightarrow 2CaO + Ca_2Si + (-660\ cal/g)$

$3Ca + 2CaCrO_4 + 2LiCl \rightarrow 2Ca_2CrO_4Cl + CaLi_2 + (-1770\ cal/g)$

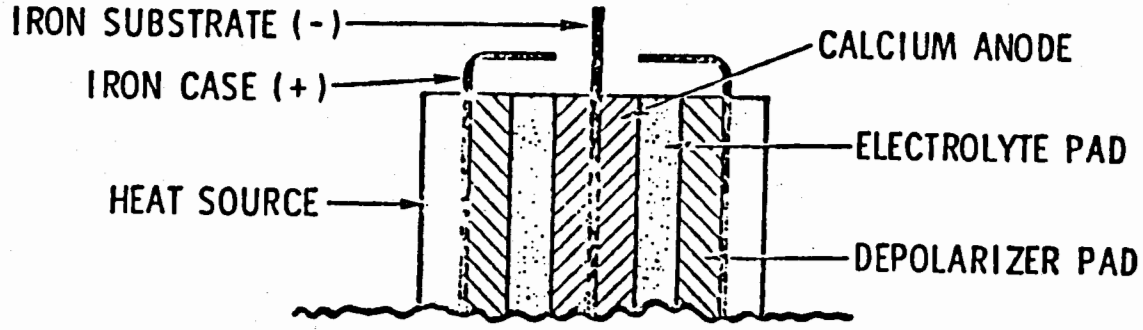
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CONVENTIONAL CELL



CELL CASE

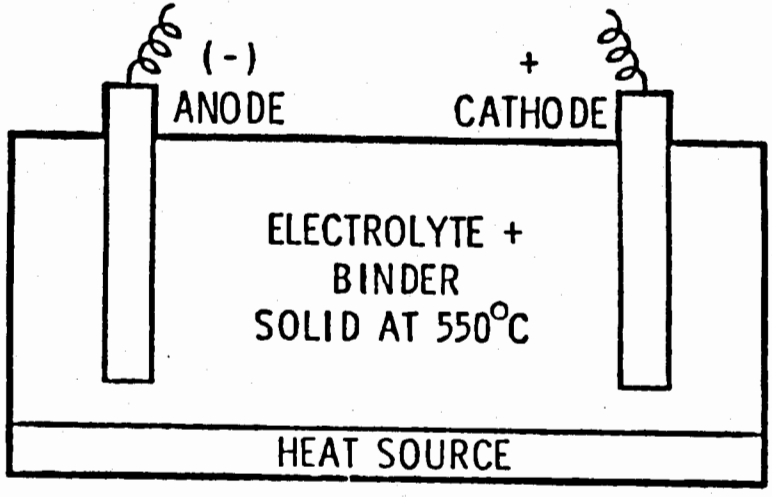
ANODE - CALCIUM METAL ON IRON SUBSTRATE
CATHODE - CALCIUM CHROMATE (DEPOLARIZER)
ELECTROLYTE - LITHIUM CHLORIDE, POTASSIUM CHLORIDE
HEAT SOURCE - ZIRCONIUM-BARIUM CHROMATE
CELL CASE - IRON



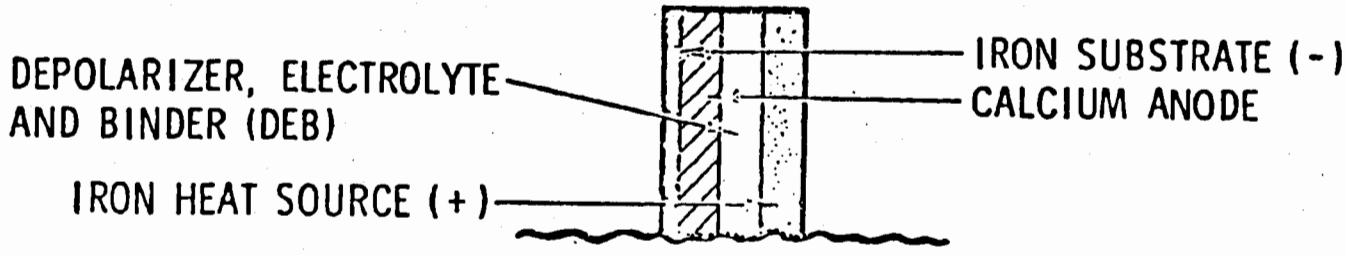
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NEW PELLETIZED CELL



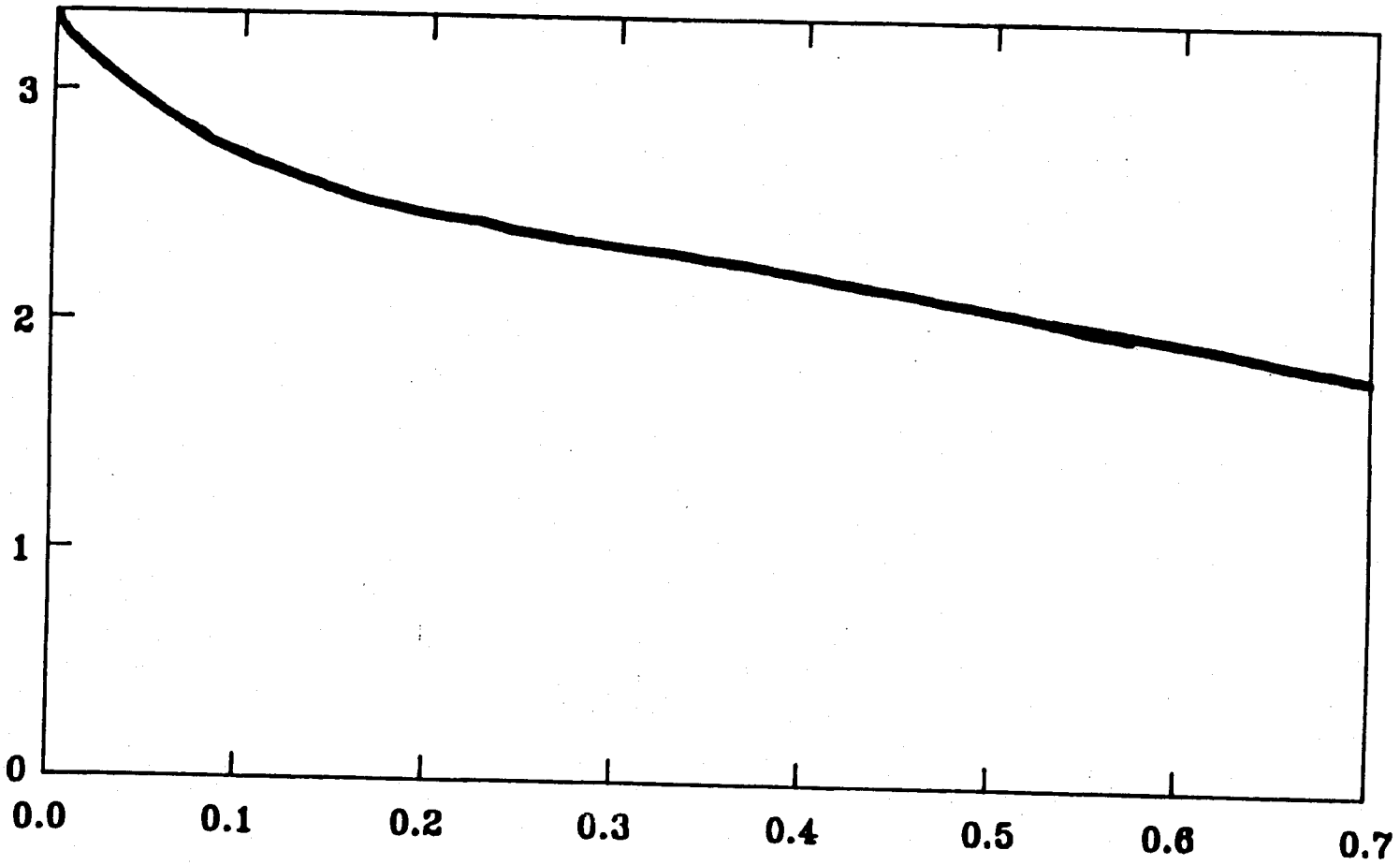
ANODE - CALCIUM ON IRON SUBSTRATE
CATHODE - CALCIUM CHROMATE (depolarizer)
ELECTROLYTE - LITHIUM CHLORIDE, POTASSIUM CHLORIDE + SiO_2 BINDER } DEB
HEAT SOURCE - IRON-POTASSIUM PERCHLORATE DISC
CELL CASE - NONE



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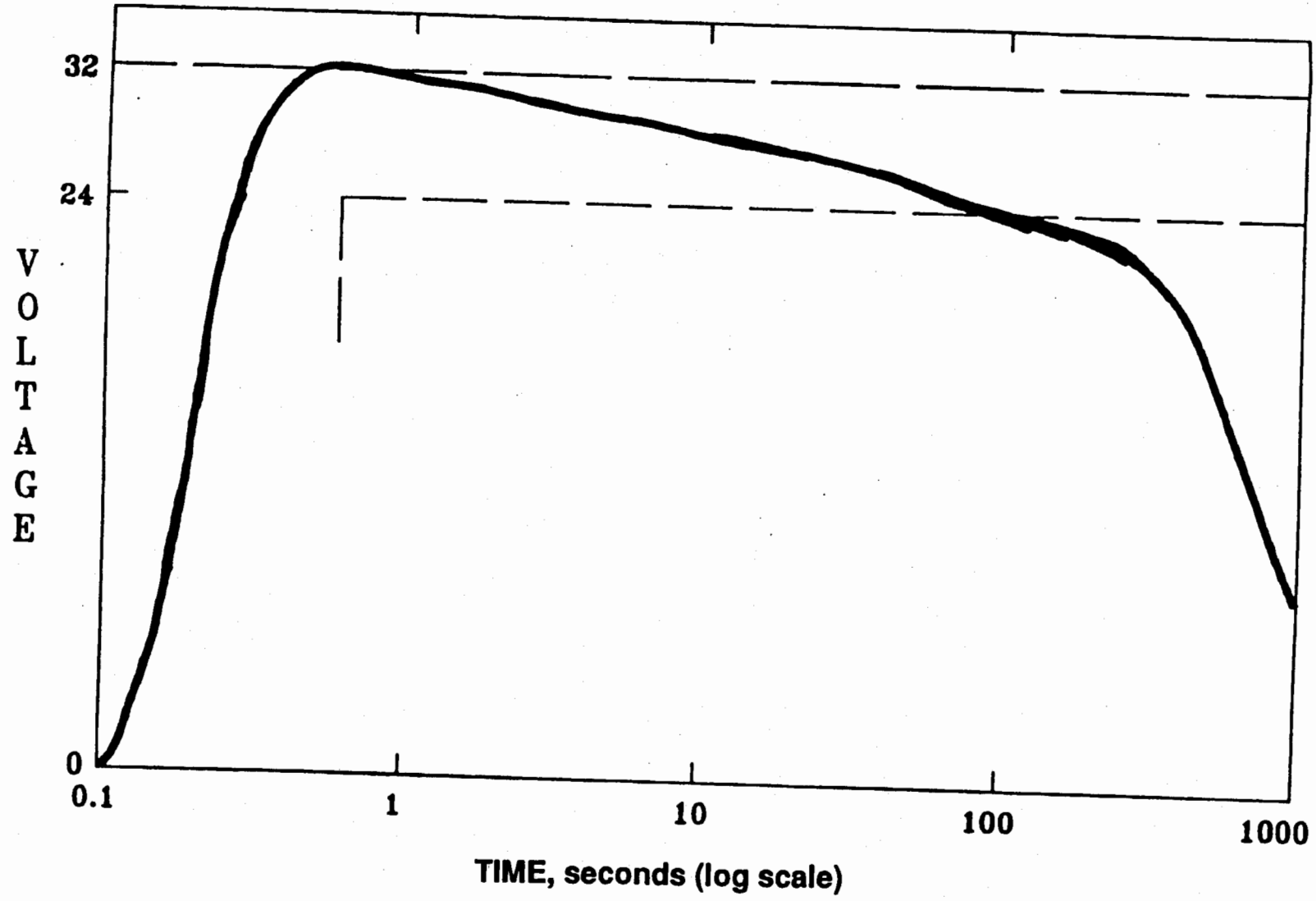
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Cell Voltage vs Current Density
Typical Thermal Battery



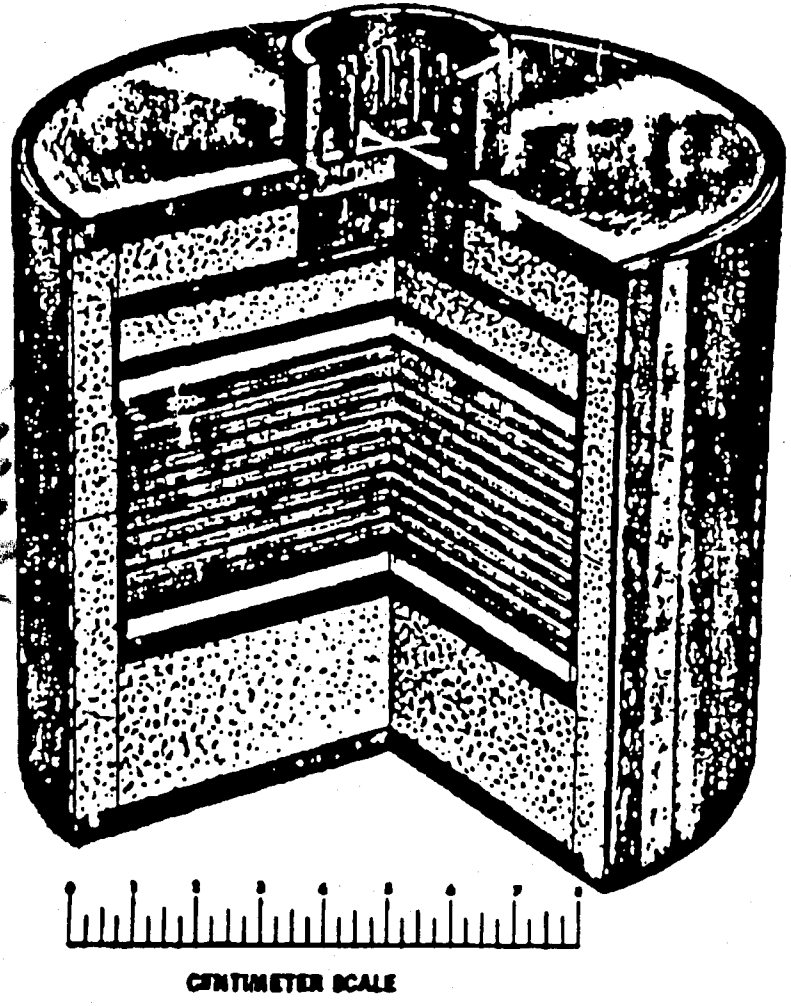
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Typical Thermal Battery Performance--
Constant Load



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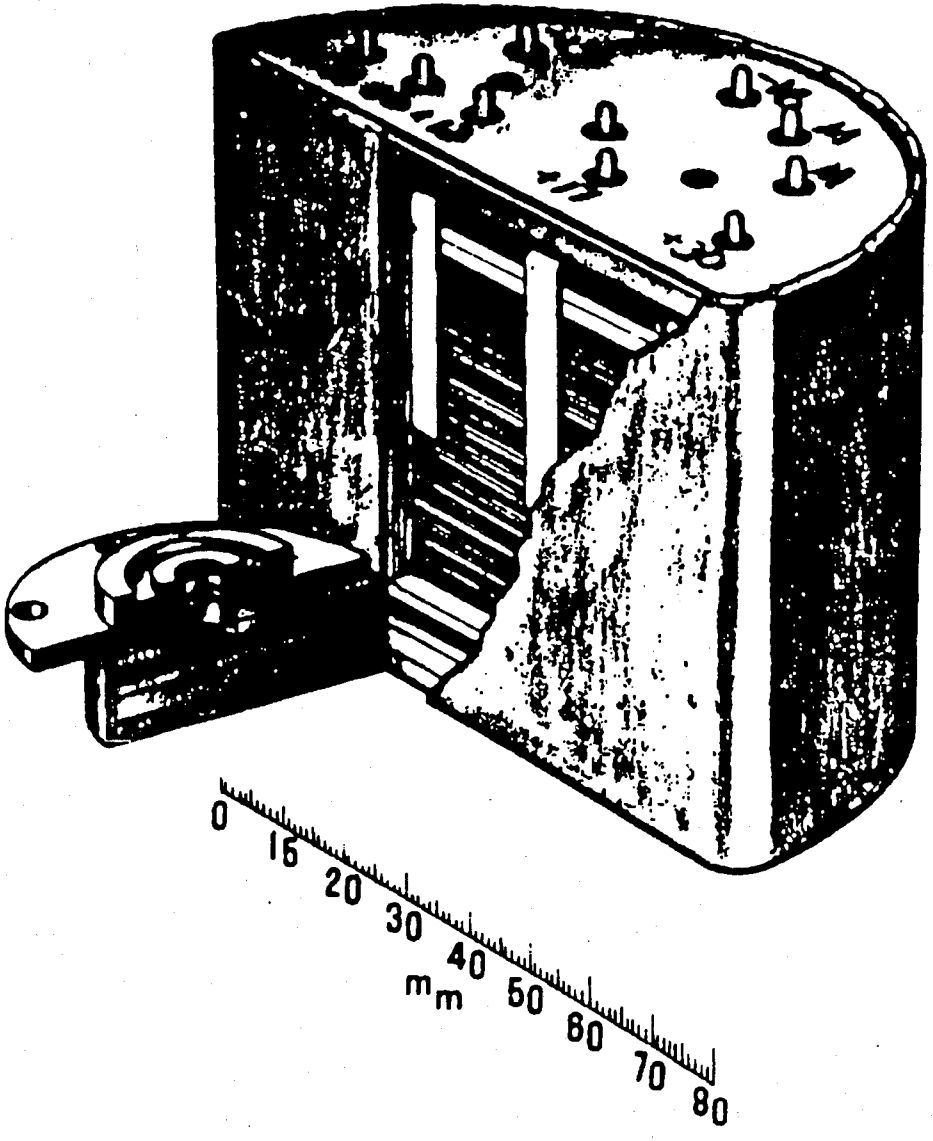


- THERMAL INSULATION (Min-K)
- HEAT SOURCE ($Fe+KClO_4$)
- HEAT OF FUSION HEAT SINK ($NaCl-Li_2SO_4$)
- CALCIUM ANODE
- DEB
  - DEPOLARIZER ($CaCrO_4$)
  - ELECTROLYTE (LiCl, KCl)
  - BINDER (SiO_2)
- HEAT PAPER ($Zr+BaCrO_4$)

THERMALLY ACTIVATED BATTERY

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MC2936 THERMAL BATTERY



DEPOLARIZER-ELECTROLYTE-BINDER (DEB)

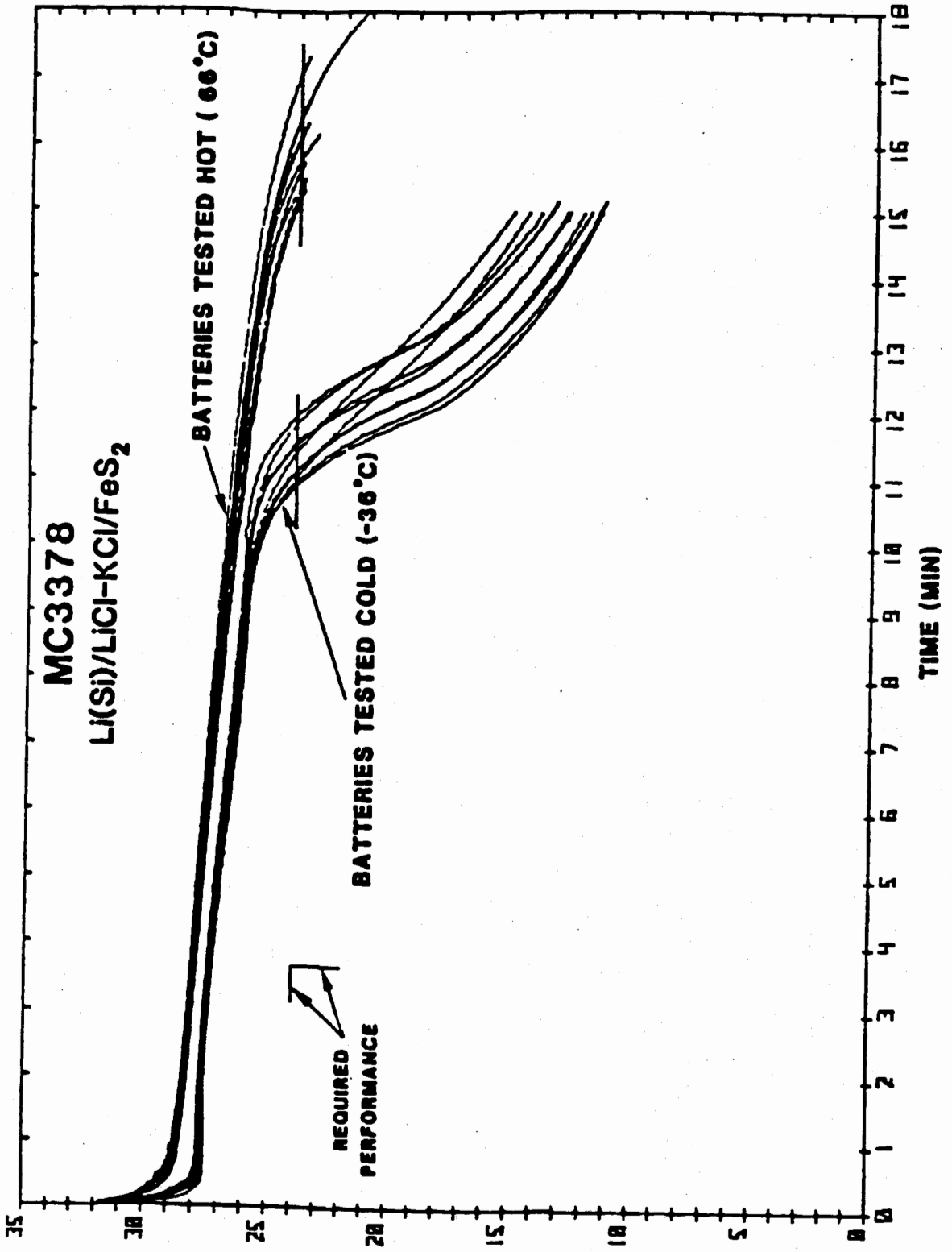
HEAT PELLET & INTER CELL CONNECTOR (Fe-KCl O_4)

NEGATIVE ELECTRODE (Ca)

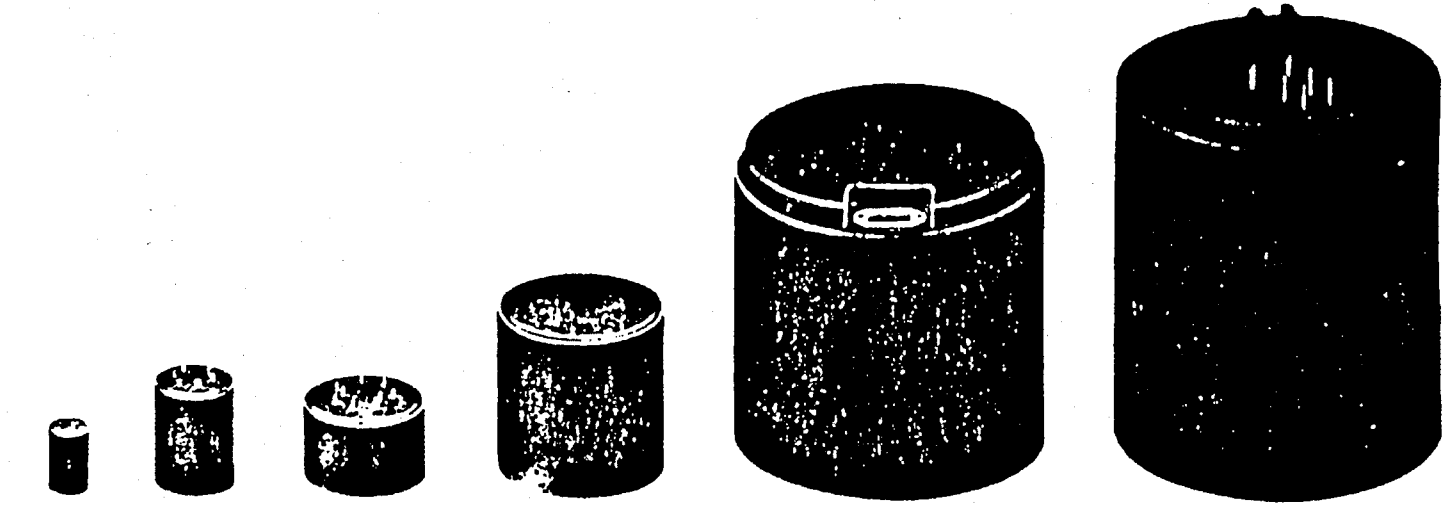
HEAT PAPER

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MC3378
Li(Si)/LiCl-KCl/FeS2
BATTERIES TESTED HOT (66°C)
BATTERIES TESTED COLD (-36°C)
REQUIRED PERFORMANCE
TIME (MIN)
35
30
25
20
15
10
5
0
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

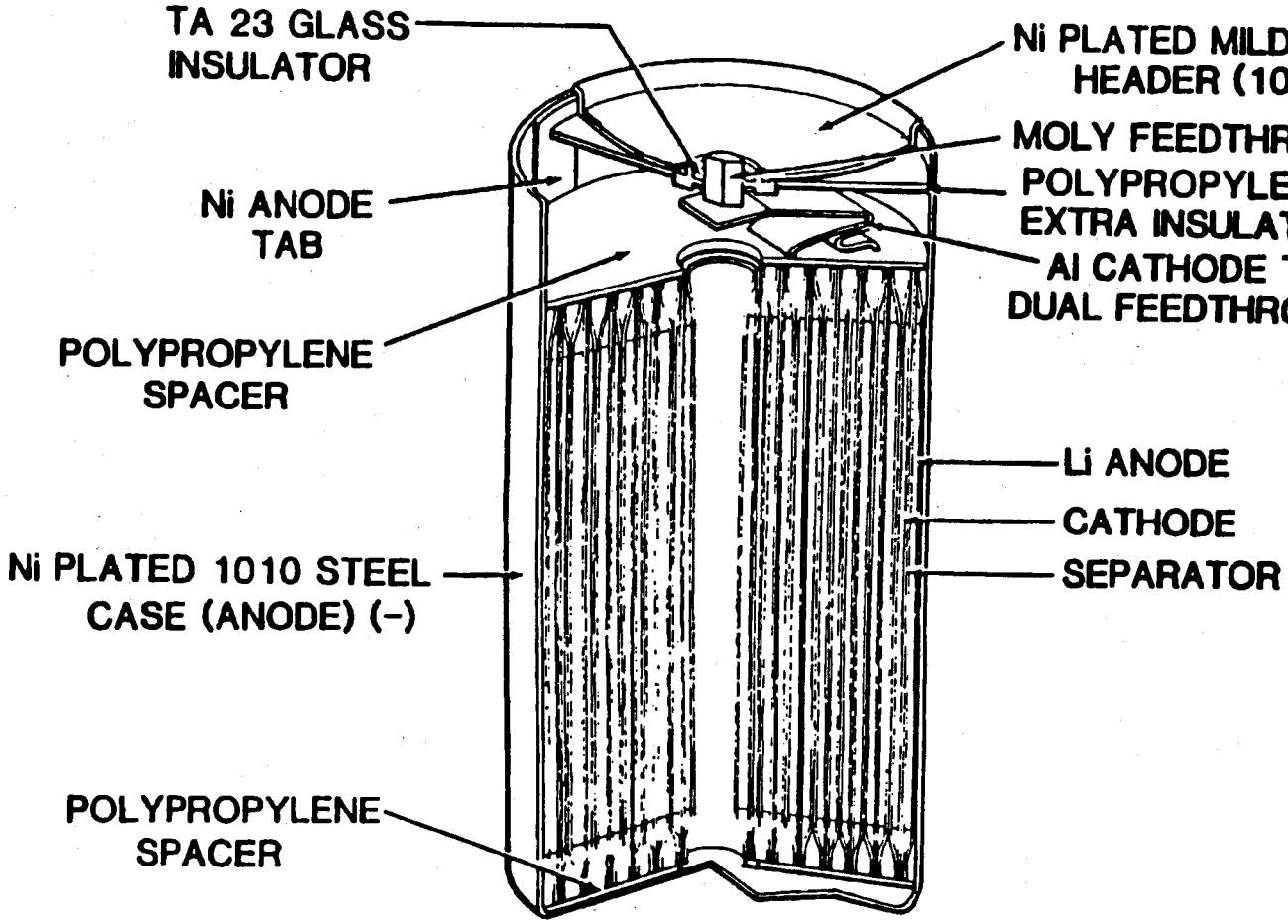
Li(Si)/FeS_2 SYSTEM BATTERIES



PULSE	SPIN	MULTIVOLTAGE	LONGLIFE	INSTRUMENTATION	HIGH CURRENT
fast rise 40 amps for 600 mst	operates at 18,000 rpm	5 voltages over a 5.1 current density range	.35 amps for 1 hour in 400 cm^3 volume	3.2 amps for 1½ hours	30 amps for 30 minutes

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SANDIA MODIFIED
DURACELL INTERNATIONAL
Li/SO_2 'D'CELL

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A REVIEW OF THERMAL BATTERY TECHNOLOGY

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Sandia Laboratories
Albuquerque, New Mexico

ABSTRACT

This report reviews the evolution of thermal battery technology from World War II to the present. It discusses the first applied work with thermal cells, the transfer of this laboratory technology to the United States, the development of the initial cup technology by the U. S., and the evolution of this technology to the later pellet technology. The paper by P. Tepper will then discuss the performance of thermal batteries and compare this performance with that of other ordnance batteries.

INTRODUCTION

The electrochemical power sources used in nuclear weapons to date have been lead-acid, nickel-cadmium, silver-zinc, and thermal batteries. The lead-acid battery was used in the first atomic bomb and in later weapon systems until 1953, when it was replaced by the nickel-cadmium battery, followed shortly by the silver-zinc battery. These aqueous electrolyte batteries all had a critical deficiency: their wet stand time was so short that either the battery had to be frequently recharged or the electrolyte had to be carried separately and injected into the battery just before its use. The thermally activated battery, introduced in 1955, solved the wet stand problem. Since then, it has been the sole power source used by Sandia Laboratories for nuclear weapon systems.

The thermal battery is so called because it contains a pyrotechnic heat source that, when ignited, thermally activates the battery by melting the electrolyte, which is a salt mixture. Salt mixtures are solid and chemically inert at room temperature, but when fused become fluid and highly conductive. These properties of the electrolyte provide the long shelf life and good electrical performance of the thermal battery (1,2).

The origin of the thermal battery dates back to World War II when Dr. Ing. Georg Otto Erb, working in Germany, developed the first practical cells, using a salt mixture as an electrolyte. Dr. Erb investigated the performance of several couples and electrolytes, the effects of salts with water of hydration, and the effects of water in unhydrated electrolyte salts. He also conceived and developed batteries for several ordnance applications, including the V-I and V-II rockets and artillery fusing systems; however, none of these batteries was produced for field use. Dr. Erb was interrogated by British Intelligence at the end of the war and his studies were reported to them in a paper entitled "The Theory and Practice of Thermal Cells" (3,4). This information was conveyed by the British, and possibly through other channels, to the United States Ordnance Development Division of the National Bureau of Standards, which later became Harry Diamond Laboratories (HDL). In this paper the authors will discuss only the channel for which documentation is presently available.

Prior to August 1946 (5) Mr. Grenville Ellis, U. S. Signal Corps (now the U. S. Army Electronics Command) brought copies of Dr. Erb's report to a meeting of the Joint Battery Advisory Committee. This committee of about ten people representing the Navy, Army, Air Force, and Industry met informally to exchange ordnance battery information. Dr. A. G. Hellfritzsch, of the Naval Ordnance Laboratory and a member of this committee, recognized the relevance of Dr. Erb's work to the battery needs of the VT (Variable Time) Fuze Panel under the National Research and Development Board. Dr. Hellfritzsch conveyed this report to Roger W. Curtis, who was chairman of the VT Fuze Panel and was also in the Ordnance Development Division of the National Bureau of Standards (6). Within a few weeks Curtis and his co-workers had demonstrated the capabilities of thermal cells for ordnance applications. Combining this with the work under contract to Catalyst Research Corporation to develop gasless pyrotechnics, they developed a self-contained thermal battery (6).

In the late forties the Wurlitzer Corporation began production of HDL's first thermal battery. This battery was used in a mortar round and the total production reached over a million batteries (7).

In 1952 Curtis reported on thermal battery technology at a symposium attended by various ordnance groups (8). Because of its desirable ordnance characteristics, the thermal battery system was adopted by the military for ordnance applications and by the U. S. AEC for nuclear weapon systems.

The early thermal battery designs are frequently referred to as "cup," "pad," "cup and cover," "closed-cup," and "conventional" batteries. These early batteries had three distinguishing characteristics: heat-paper pads, electrolyte and depolarizer pads, and intercell electrical connectors, which are discussed in more detail later. These three characteristics distinguish the earlier batteries from the later pellet-type batteries

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which use heat powder pellets, electrolyte-depolarizer pellets, and an intercell connectors. The evolution from the earlier batteries to the present pellet-type batteries was gradual, and there were several hybrid batteries which included both technologies, such as the Naval Ordnance Laboratory/Eureka-Williams battery which was the first to use a pellet.

This review describes the early cup technology (9,10,11), one of the later hybrid systems (2,10,12), and the present pellet technology (11,13,14). Performance characteristics of the thermal battery are discussed with reference to the Ca/LiCl-KCl/$CaCrO_4$ electrochemical system and the pellet technology which is the principal system used by this Laboratory. Discussion of other electrochemical systems and references to these systems are given by Jeanloz (15).

THE CUP TECHNOLOGY

Figure 1 shows the typical structure of a single cell in the cup design. In the cell are the anode, the electrolyte pads, the depolarizer pads, the cup in which these are enclosed, and a heat pad to thermally activate the cell.

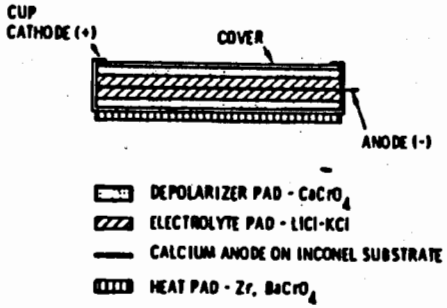


Fig. 1. - Single thermal cell - cup technology

The anode consists of calcium affixed to both sides of a metallic substrate[1] that serves both as the anode current collector and as the negative terminal by virtue of a tab extending through a slit in the side of the cell case. Although not shown in the figure, the anode is electrically insulated from the cathode cup.

The electrolyte pads are adjacent to the calcium surfaces and contain the electrolyte, the eutectic mixture of the lithium-chloride/potassium-chloride system (59 mole % LiCl-41 mole % KCl), which has a melting point of 352 C. The pads are formed by passing a fiberglass tape through a vat of molten electrolyte and punching pads from the tape after it has cooled and the electrolyte has solidified.

1. Inconel, iron, stainless steel, and nickel are the metals most often used.

The depolarizer[2] pads, adjacent to the electrolyte pads, complete the active cell stack. These pads are punched from a paper-like sheet formed by pressing and drying a slurry containing the calcium chromate depolarizer along with glass and ceramic fibers.

The active cell stack is then placed in a metallic cup, covered with a metallic disc, and the sides of the cup are crimped over the disc as a seal. The cup and disc thus hold the cell components in place and serve as the cathode current collector and positive terminal of the cell.

The last component of the single cell is the heat pad, which activates the cell by raising its temperature to the operating range of 500 to 600 C. The pad is punched from heat paper sheets formed by a process similar to that used for the depolarizer pads, but involving a slurry containing zirconium fuel and barium-chromate oxidizer instead of the depolarizer. (The slurry also contained asbestos fibers. Later, Sandia eliminated the asbestos because it releases water of hydration when heated.)

For simplicity, only the basic components of the cup cell have been described. When one includes intercell connecting tabs, wire-mesh current collectors, electrical insulators, etc., there can be as many as 27 individual parts in a cup cell as compared to the 3 parts of the later pellet cells.

It should also be noted that with the cup technology, as well as with the pellet technology, most of the battery materials either absorb or react with water, particularly the electrolyte which is very hygroscopic. Since battery performance is severely degraded if the components are exposed to water vapor concentrations greater than 1500 ppm[3], all processes are carried out in dry rooms. At this Laboratory for example, the dry rooms are maintained at less than 300 ppm; and in addition, all battery components are vacuum dried at 100 C prior to assembly.

Figure 2 illustrates thermal battery construction using the single cell described above. The active battery stack is formed by first welding the appropriate number of cells together, the negative tab of one to the positive case of the next, and then inserting a heat pad between each pair of cells to heat them and to insulate them from each other electrically. Electrical leads are attached and a narrow fuse strip of heat paper is laid up the side of the stack and across the top cell. The stack is then capped on each end

2. Depolarizer is an historic battery term used to identify the active cathode material which is reduced electrochemically during battery discharge.

3. At 25 C, 1500 ppm is 5% relative humidity.

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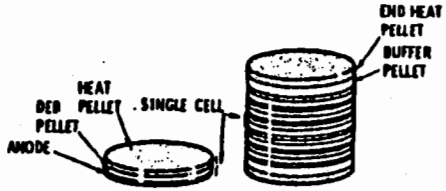


Fig. 5. - Single cell and battery stack - pellet technology

lithium-sulfate/sodium-chloride eutectic, which melts at 493 C and has a heat-of-fusion of about 84 calories per gram. Part of the heat from the end heat pellets is used to melt the eutectic salt in the buffer pellet. When the end of the battery stack cools to 493 C, the eutectic solidifies and releases its heat-of-fusion to maintain the battery temperature for a longer time.

As shown in Figure 6, the assembly of a pellet thermal battery is completed with the addition of electrical leads, match, fuse train, insulation, and battery case. The thermal insulation used is Fiberfrax for regular applications and Johns-Manville's Min-K 2002 for long-life applications. The Min-K 2002 was originally developed under AEC contract for thermoelectric generators and selected for thermal batteries after an extensive evaluation program (13,14). It is composed of silica, quartz fibers, and titanium dioxide.

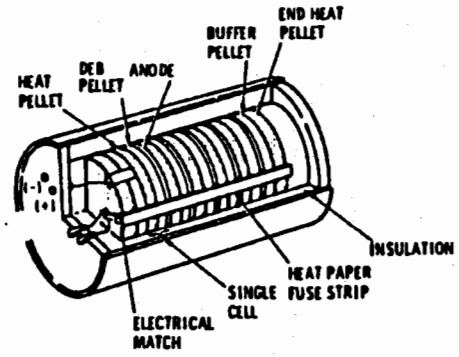


Fig. 6 - Thermal battery construction - pellet technology

Figure 7 shows the steps of battery construction and the use of center bolt construction to ensure concentricity of the plates. In this construction, a quartz-covered steel bolt is passed through center holes in the battery stack and two steel end plates. The result is a concentric, integral, rugged subassembly that can be easily handled and inspected.



Fig. 7 - Thermal battery - pellet technology

The pellet battery offers several improvements over the cup battery: longer activated life, more reproducible performance, greater ruggedness, no intercell connectors, lighter battery cases, better control of materials and processing, simplified fabrication, reduction of inspection and testing, elimination of hazardous heat pads, and lower cost. In addition, the pellet battery design is simpler and thus more amenable to investigation. This in turn has led to improved performance and further advancements, particularly with respect to longer life. Production has been completed on a thermal battery having an activated life of 15 minutes (21) and exploratory thermal batteries under development at Sandia have demonstrated activated lives of over 60 minutes (22).

ACKNOWLEDGEMENTS

The authors acknowledge the assistance of the individuals who provided much of the information concerning the early history of thermal batteries: A. Attewell of the Royal Air Force Establishment in the British Ministry of Defense, E. V. Foreman and C. W. Jennings of Sandia Laboratories, B. Kaplan of Harry Diamond Laboratories, R. T. Mead of Wilson Greatbatch, Ltd., R. D. Walker of the University of Florida, I. D. Yalen of the Naval Ordnance Laboratory, and particularly A. G. Hellfritsch of the Naval Ordnance Laboratory.

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DETONATORS

- EXPLOSIVE/BRIDGEWIRE (EBW)
- SLAPPER — LOS ALAMOS
- SLAPPER — SANDIA
- SLAPPER — LAWRENCE
- CODED EXPLOSIVE LOGIC SYSTEM (CELS)
- MECHANICAL SAFING ARMING DETONATOR (MSAD)
- DETONATOR SAFING STRONG LINK (DSSL)

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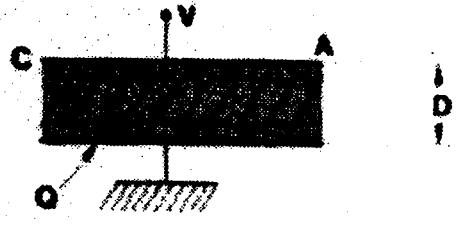
Typical Range of Controlling Parameters for Firing System Design

Characteristic	Minimum	Maximum
Electrical		
Input Voltage	24V	36V
Output Voltage (Operating)	400V	6000V
Output Current	600 Amps	640,000 Amps
Voltage Regulation	± 2%	± 10%
Loads	Single	Multiple
Charge Time	300 ms	5 seconds
Arm Time	1 second	20 years
Output Energy	.5 joule	5790 joules
Reliability	.992	.9995
Normal Environment		
Operating Temperature	-65°F	+170°F
Exposure Temperature	-80°F	+200°F
Shock	100g	18,000g
Vibration	.05 g^2/Hz	2 g^2/Hz
Angular Acceleration	—	289,000 rad/sec^2
Spin Rate	—	16,350 rpm

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BASIC LINEAR CIRCUITS FOR ELECTROMECHANICAL ENERGY CONVERSION

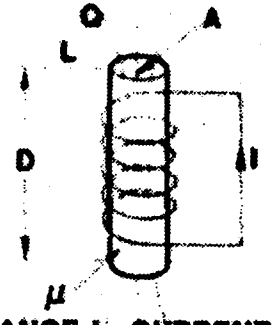
OPEN CIRCUITED CAPACITOR



CAPACITANCE C, VOLTAGE V, AND CHARGE Q ARE CONNECTED BY

$$Q = C \times V$$

FOR LOSSLESS CHANGES, CHARGE Q IS CONSERVED--A WELL KNOWN FACT



INDUCTANCE L, CURRENT I, AND FLUX LINKAGE θ ARE CONNECTED BY

$$\theta = L \times I$$

FOR LOSSLESS CHANGES, FLUX θ IS CONSERVED, WHICH IS NOT WIDELY KNOWN

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The Energy Stored in the Systems

$$E = \frac{CV^2}{2} = \frac{Q^2}{2C}$$

$$E = \frac{LI^2}{2} = \frac{\phi^2}{2L}$$

With Q and ϕ Constant, We Gain Energy, If

$$C = \frac{\varepsilon A}{D}$$

$$L = \frac{\mu A}{D}$$

Are Decreased By:

- Pulling Plates Apart (Van de Graph)
- Pulling Dielectric Out
- Decreasing Dielectric Constant by Lattice Destruction (Ferroelectric Pulse Generator)
- Pushing Wires Apart
- Pulling Core Out
- Continuously Shorting Out Turns (Wire Coil Flux Compressor)
- Collapsing System (General Flux Compression)

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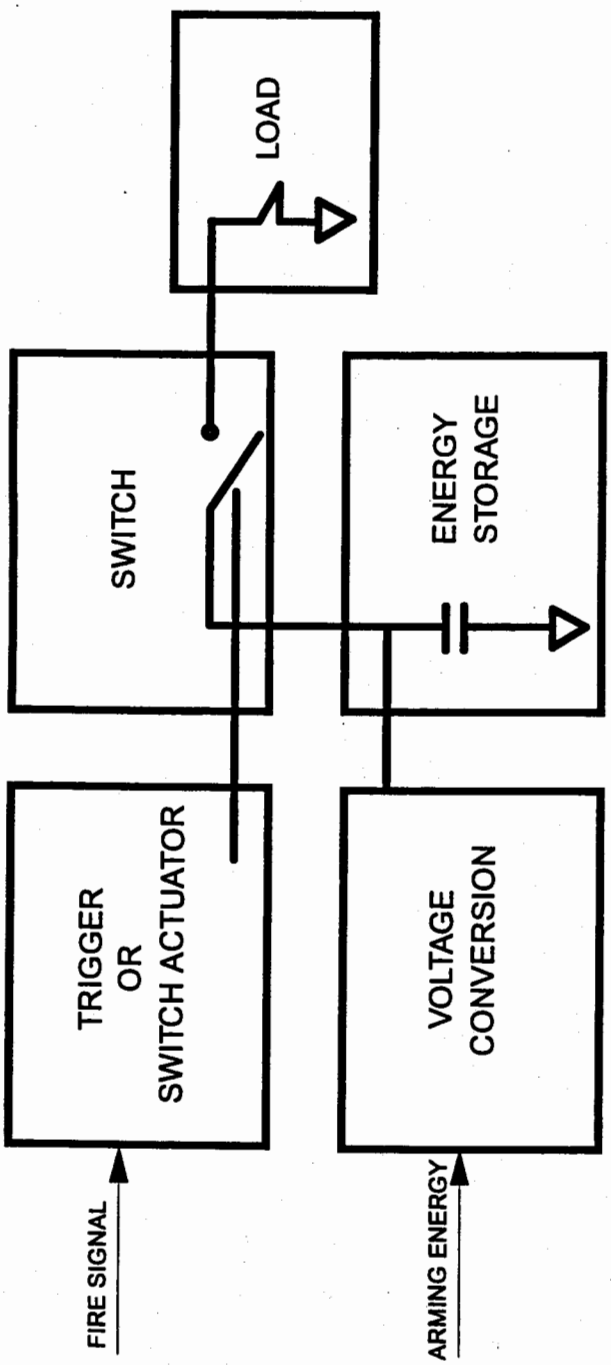
Firing Set Types (U)

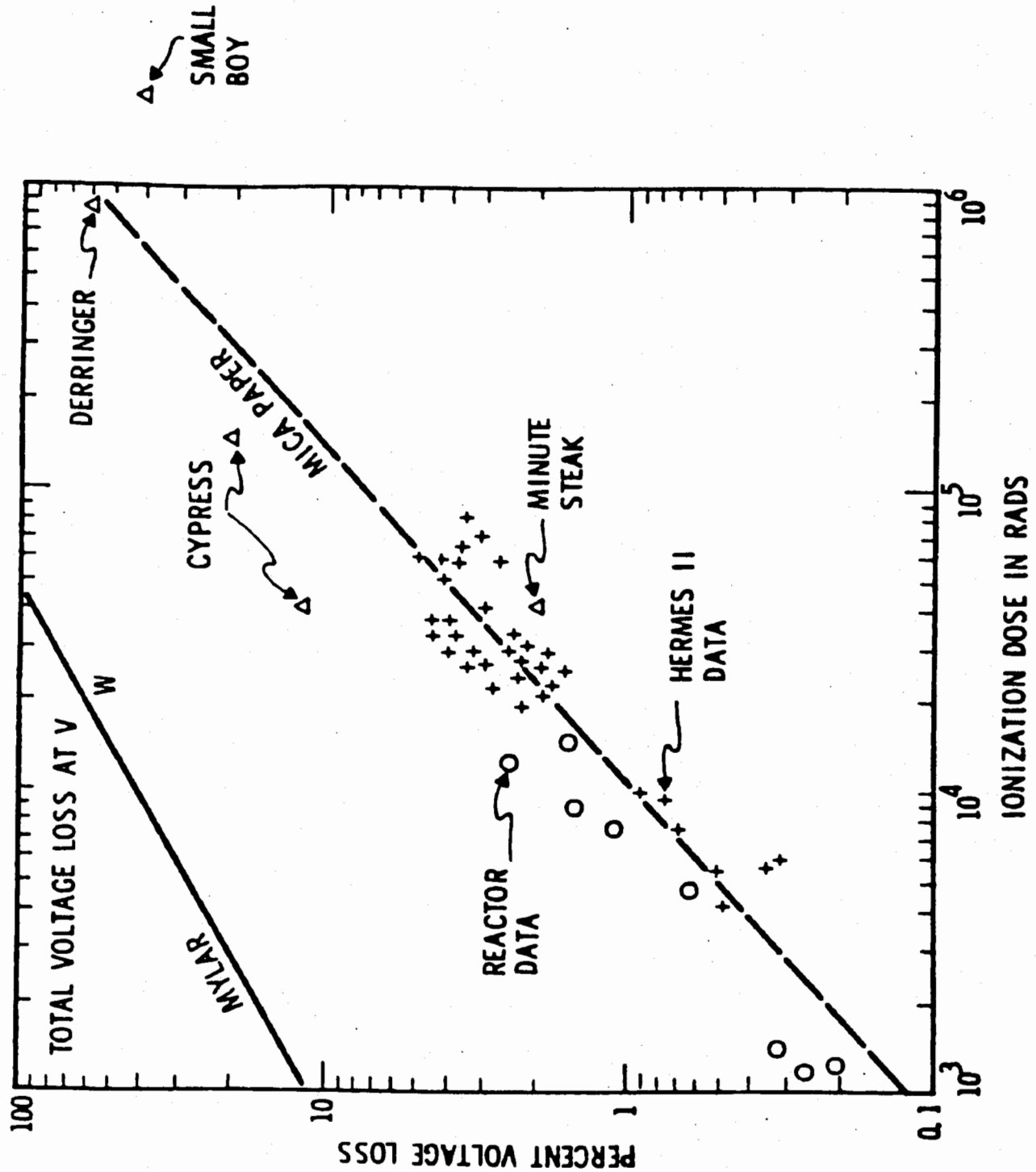
CDU — Capacitor Discharge Unit

In its simplest form, the CDU consists of a device for supplying the energy to charge a capacitor upon receipt of arming signals and also a switch of some sort for discharging this energy through the detonators upon receipt of a firing signal.

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LOAD
SWITCH
ENERGY STORAGE
TRIGGER OR SWITCH ACTUATOR
VOLTAGE CONVERSION
FIRE SIGNAL
ARMING ENERGY


SMALL BOY
DERRINGER
CYPRESS
MICA PAPER
MINUTE STEAK
HERMES II DATA
REACTOR DATA
W
MYLAR
TOTAL VOLTAGE LOSS AT V
PERCENT VOLTAGE LOSS
IONIZATION DOSE IN RADS
100
10
1
0.1
10^3
10^4
10^5
10^6

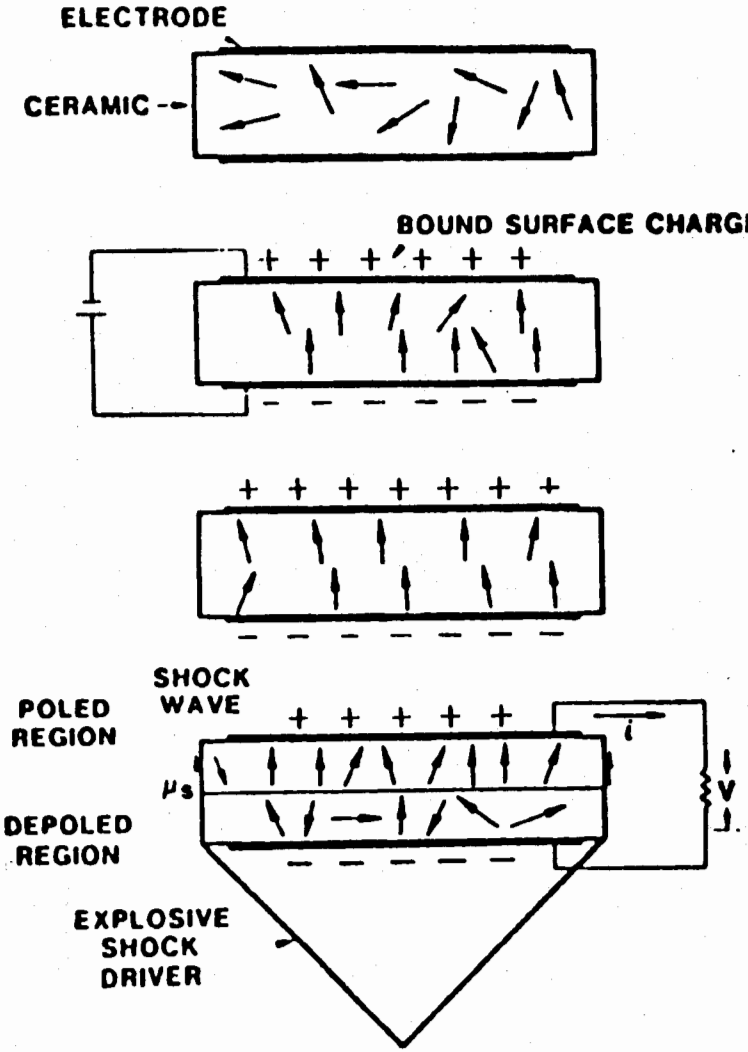
Firing Set Types (U)

FE — Ferroelectric

The FE firing set consists of an explosive plane wave generator and a poled ferroelectric ceramic element. A pressure pulse produced by detonation of the explosive in the plane wave generator causes the release of bound charge from the ceramic element in the detonator load. This technology is also used as the power source in explosive neutron generators.

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THEORY OF OPERATION PRE-ARMED FE



UNPOLED

Polycrystalline Multidomain Ferroelectric Ceramic

POLING PROCESS

Domains aligned (as allowed by crystallographic directions) by impressing external electric field

POLED CERAMIC

Dipoles remain aligned in absence of disturbing independent variable. Bound surface charge remains due to internal electric field

SHOCK DEPOLING PROCESS

Shock wave randomizes dipoles (domains) eliminating internal field, thus freeing bound charge to external circuit.

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Firing Set Types (U)

SFE — Slim Loop FE

The SFE firing set is similar to the FE, but its poling voltage is provided by an external power source in a manner similar to the CDU energy storage capacitor. This technology is used on the Mk3, Mk4, and Mk12A.

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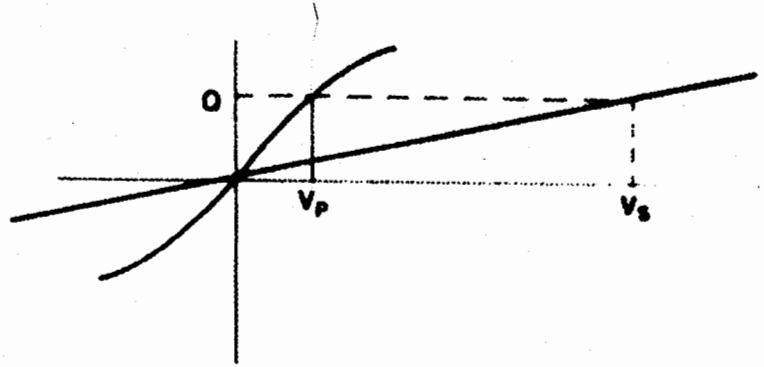
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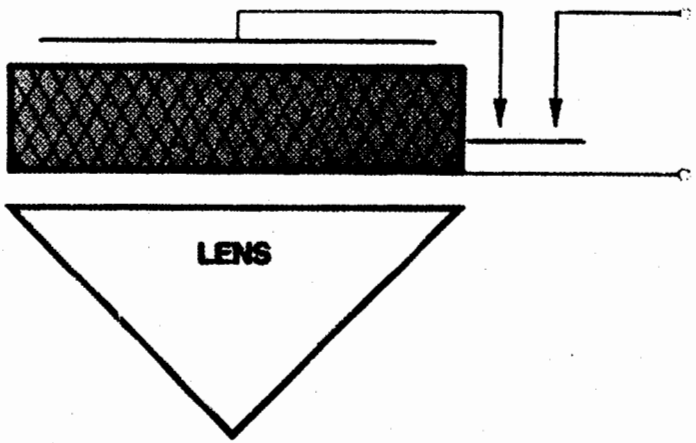
THEORY OF OPERATION ARMABLE SFE

$$Q = \text{CONSTANT}$$

$$E = \frac{QV}{2}$$

$$Eg = \frac{Q(V_S - V_P)}{2}$$

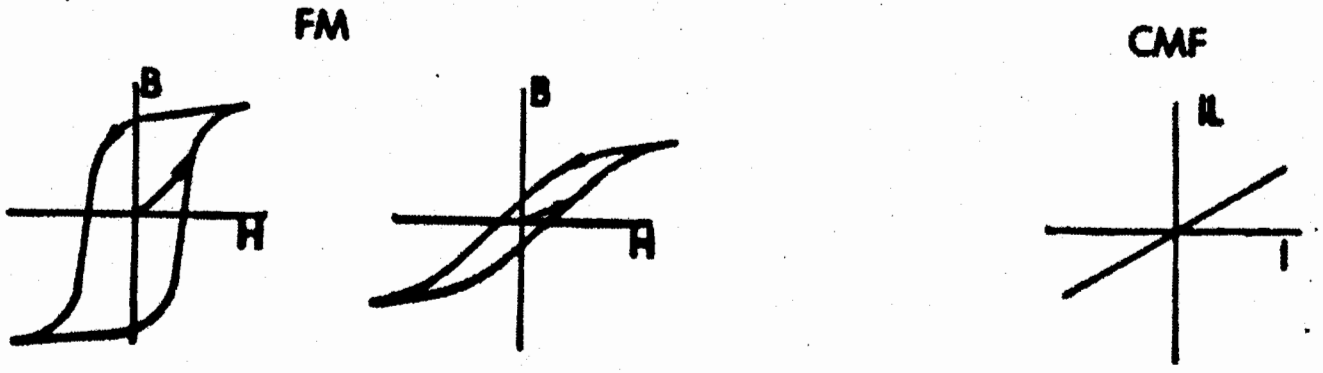


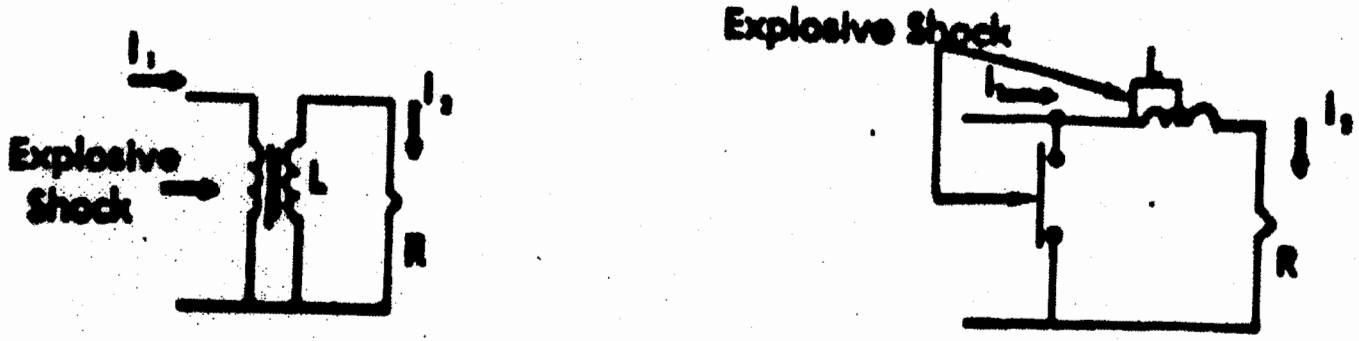


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MAGNETIC ENERGY CONVERSION





Conservation of Flux-Linkage (φ)

$$\left.\begin{aligned}\varphi_1 &= L_1 I_1\\ \varphi_2 &= L_2 I_2\end{aligned}\right\} \quad \varphi_1 = \varphi_2 \quad \left.\begin{aligned}&\\ L_1 I_1 &= | L_2 I_2 |\end{aligned}\right\} \quad I_2 = I_1 \frac{L_1}{L_2}$$

$$\text{Energy} = 1/2\, L I^2 = 1/2\, \frac{\varphi^2}{L I}$$

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Firing Set Types (U)

FM — Ferromagnetic

The FM firing set basically consists of an explosive charge, a ring of ferromagnetic cores and excitation and load windings. Mechanical energy in an explosively driven pressure pulse is transduced into electrical energy in the load winding as the magnetic cores are demagnetized by the shock wave.

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Firing Set Types (U)

CMF — Compressed Magnetic Field

The CMF or "Lobo" firing set converts chemical energy stored in explosive to electro-magnetic energy through magnetic flux compression. A CMF firing system also includes an injector to introduce an initial magnetic flux into the compression volume just prior to the compression event. This injector can be a CDU, FE, FM, or SFE.

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Recent Production Firing Sets

B28	Bomb Stockpile Improvement	CDU
W31	Nike Hercules Stockpile Improvement	CDU
B53	Bomb Stockpile Improvement	CDU
B51	Bombs	CDU
W78	MK4 Reentry Vehicle	SFE
W79	8-inch Projectile	FM
W80	Cruise Missiles	CDU
B83	Bomb	CDU
W84	Ground Launched CM	CDU
W87	MX (Peacekeeper)	CDU
W88	Mk5 Reentry Vehicle	CDU

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Current Production Set

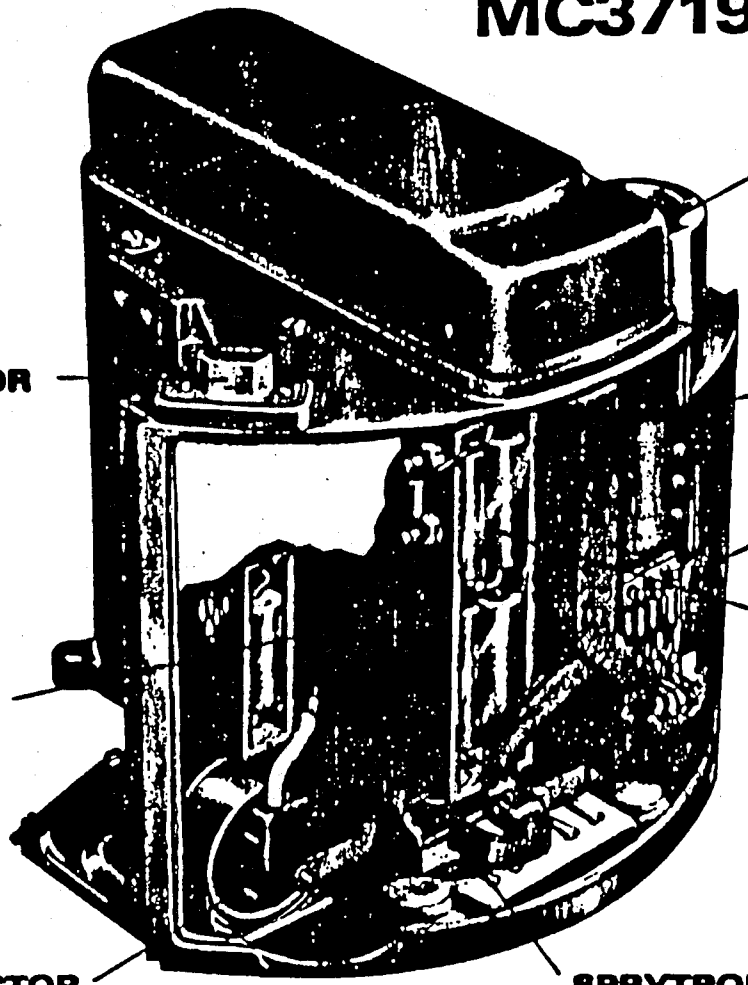
B83 **Redesign** **CDU**

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CONFIDENTIAL
MC2918
BBN-X731-K77
TP1A
TP1B
TP2A
TP2B
TP3A
TP3B
TP4A
TP4B
TP5A
TP5B
TP6A
TP6B
TP7A
TP7B
TP8A
TP8B
TP9
HIGH VOLTAGE
WARNING

MC3719 FSA



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Current Development Firing Set

Phase 3

None

Pseudo Phase 3

PRESS CM
MAST 1

Cruise Missile
B61 Type

CDU
CDU

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NEUTRON MULTIPLICATION RATE

$$\frac{dN}{dt} = \frac{XN}{T}$$

$$\frac{dN}{dt} = \alpha N$$

$$N = N_0 e^{\alpha t}$$

$\alpha < 0$ subcritical

$\alpha = 0$ critical

$\alpha > 0$ supercritical

N = number of neutrons

X = excess number of neutrons per fission

(0.5 - 1.0 assumed to equal 1.0)

T = time per fission generation

(10^{-8} sec)

= multiplication rate

(10^{8} generations/sec)

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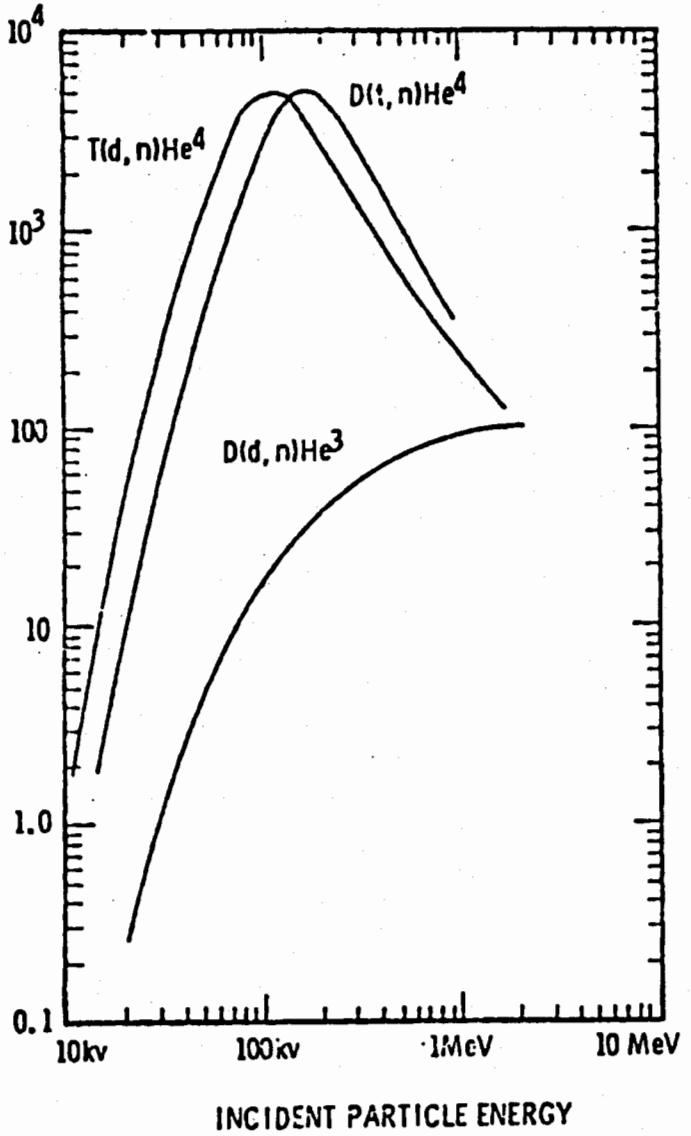


Figure 1. Reaction Cross Section Versus Incident Particle Energy

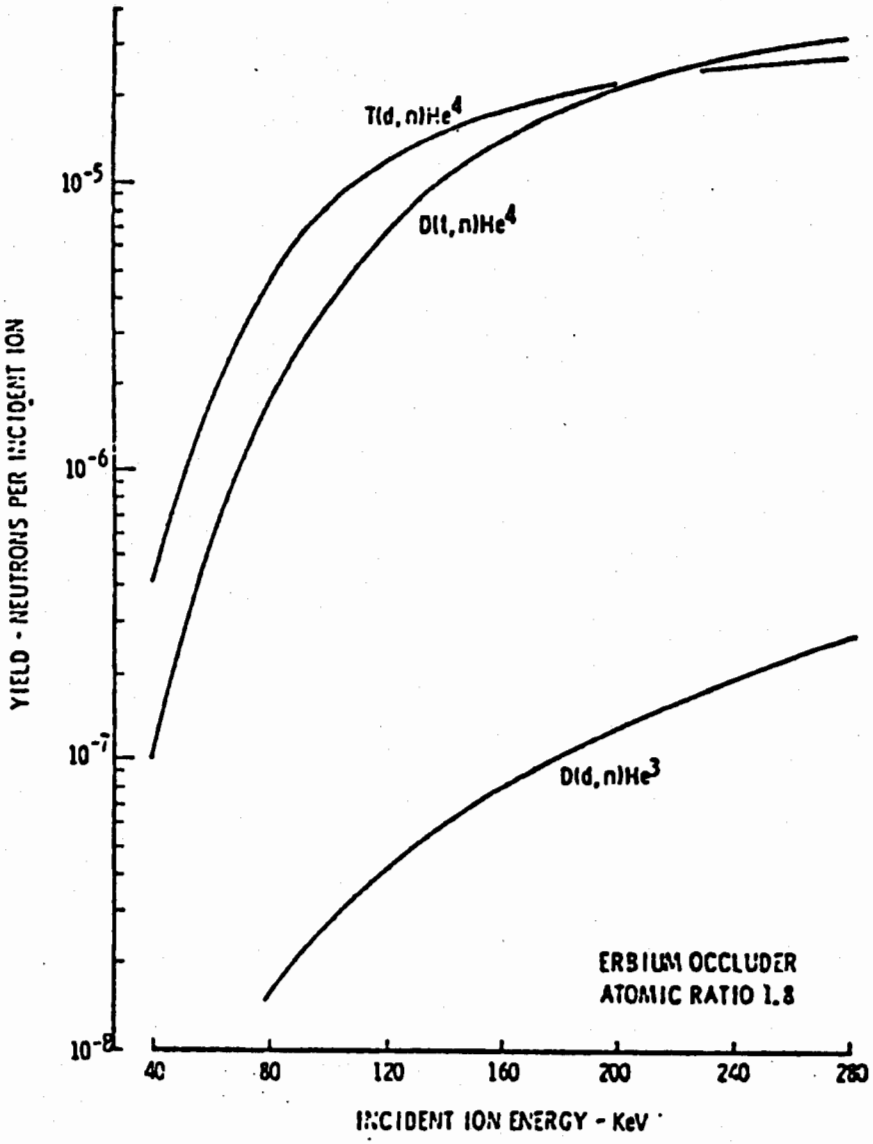


Figure 2. Theoretical Thick Target Yield

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NON-NUCLEAR IMPLOSION DIAGNOSTICS

- PHERMEX (RADIOGRAPHY)
- PIN DOME
- HIGH SPEED PHOTOGRAPHY

NUCLEAR TESTING

- WEAPON DEVELOPMENT
- EFFECTS
- VULNERABILITY AND HARDENING
- STOCKPILE RELIABILITY
- PEACEFUL NUCLEAR EXPLOSIVES

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DIAGNOSTICS

- YIELD
- "ALPHA"
- CHANNEL TEMPERATURES
- INTERSTAGE TIME
- OTHER

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REFERENCES

- LA2000 1947 SRD
- WT900 DEC 1953 SRD

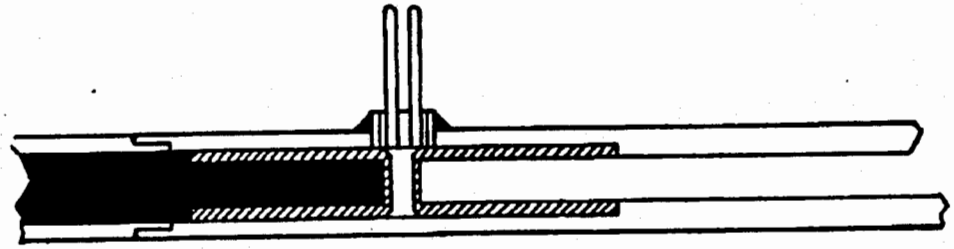
→ FIREBALL YIELD

- SAND 77-0402 - "SHOCK PROPAGATION..." SLIPHER
- DNA-119M REPORT
- DASA 1211 - 1220 REPORTS
- LLNL RESEARCH MONTHLY 3141-83-1033 (DIAGNOSTICS)
- DNA 170M REPORTS
- LASL-LLL SPECIFIC TEST REPORTS

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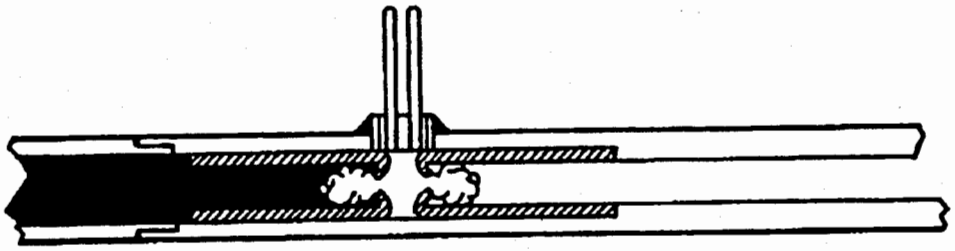
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EXPLODING DISK VALVE OPERATIONAL SEQUENCE

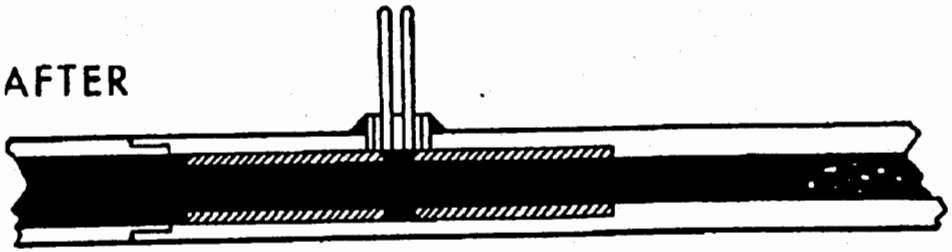


BEFORE

DURING



AFTER



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UNIQUE DESIGN PROBLEMS IN TRITIUM RESERVOIRS (U)

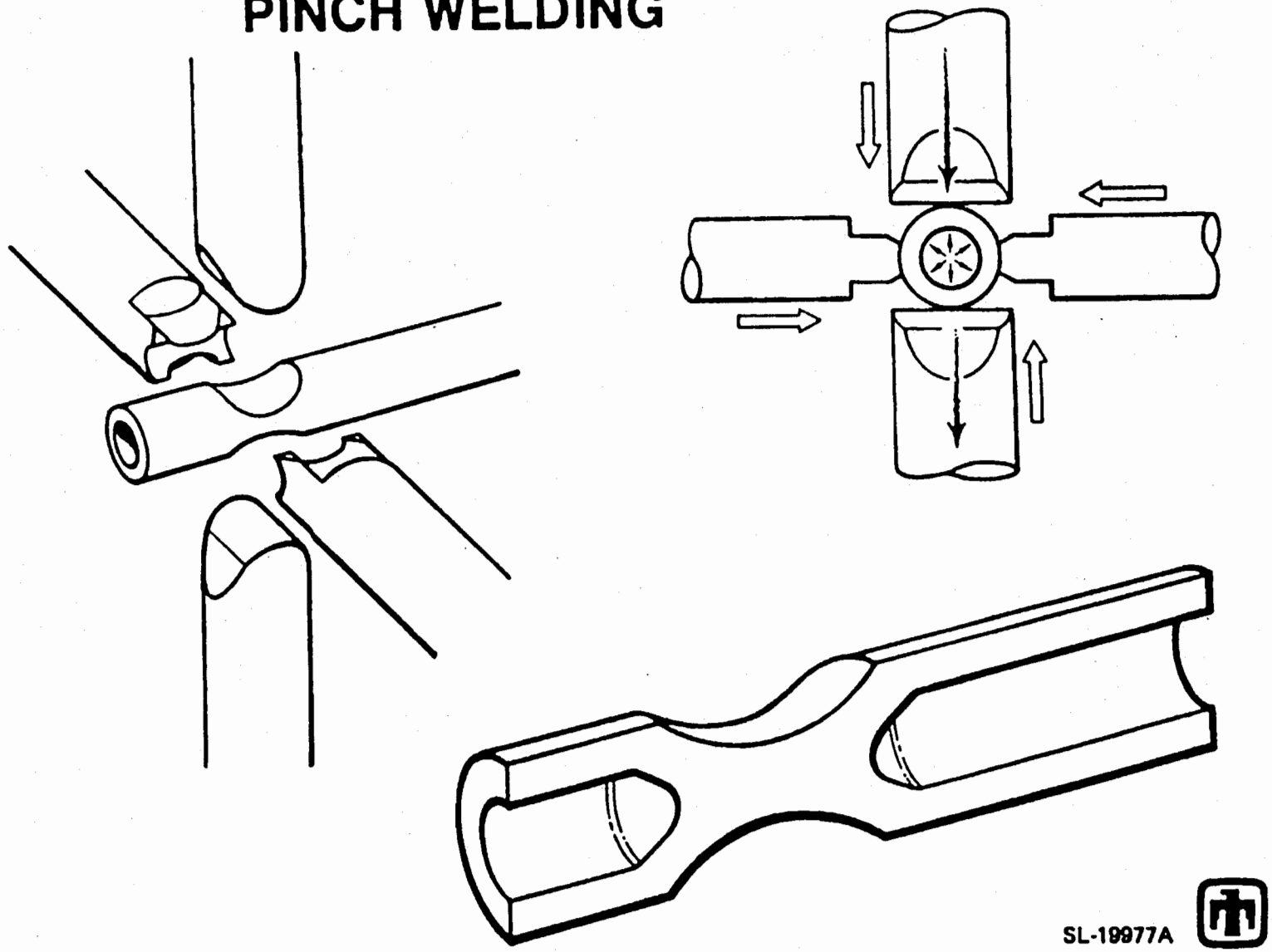
- *System*
  - Must Deliver In Specified Time
  - Must Be Consistent
  - Satisfy Weight And Space Requirements
  - Fire And Accident Considerations

- *Long Term Degradation*
  - Subject To Hydrogen Embrittlement
  - Subject To Helium Embrittlement
  - Withstand Pressure Increase With Time
  - Subject to Radiation Induced Effects (Loss of Permeability, Stoichiometry)

- *Safety*
  - Must Be Super Safe Against
    - Burst
    - Permeation (Walls, Welds, Stringers)

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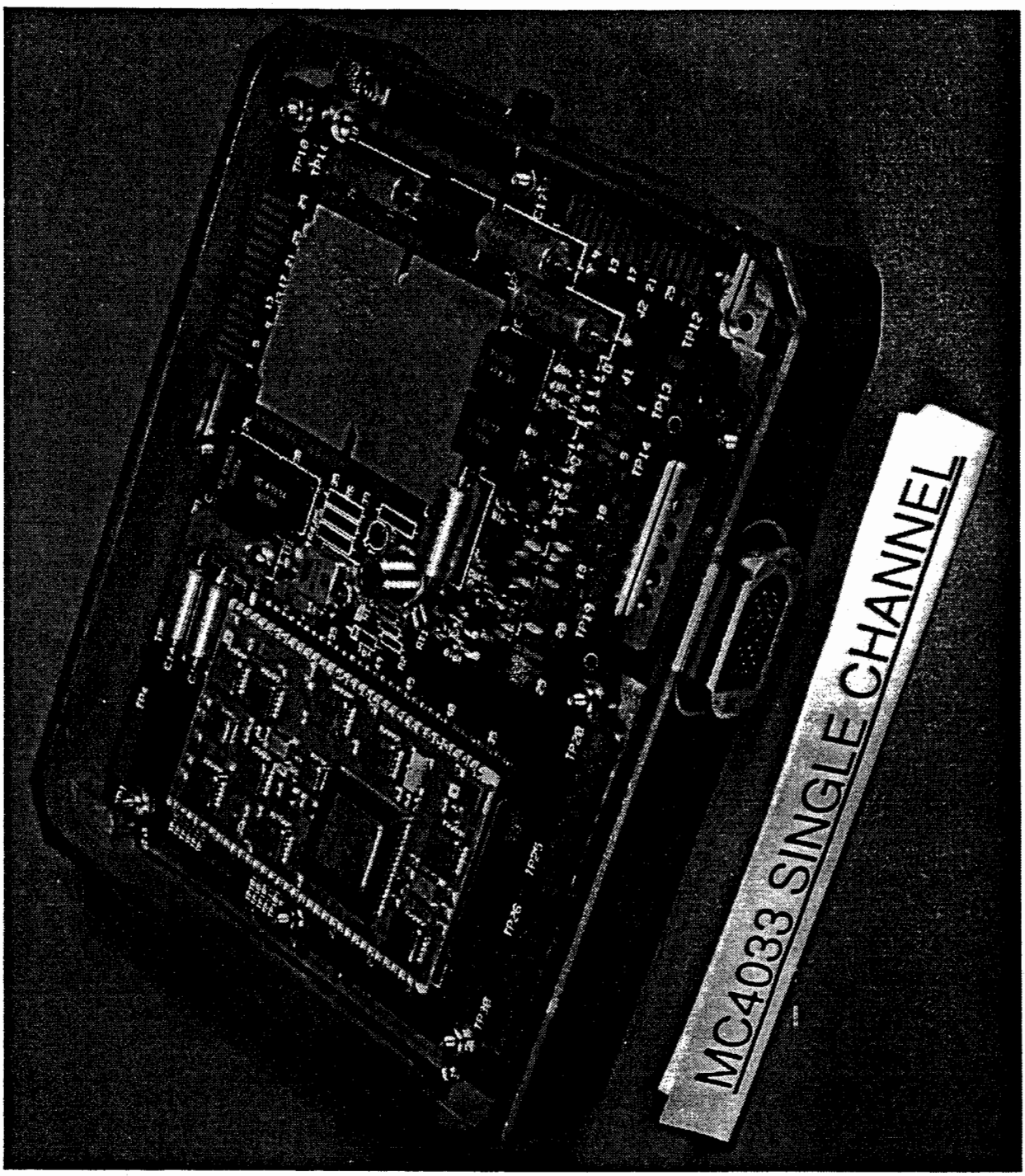
PINCH WELDING



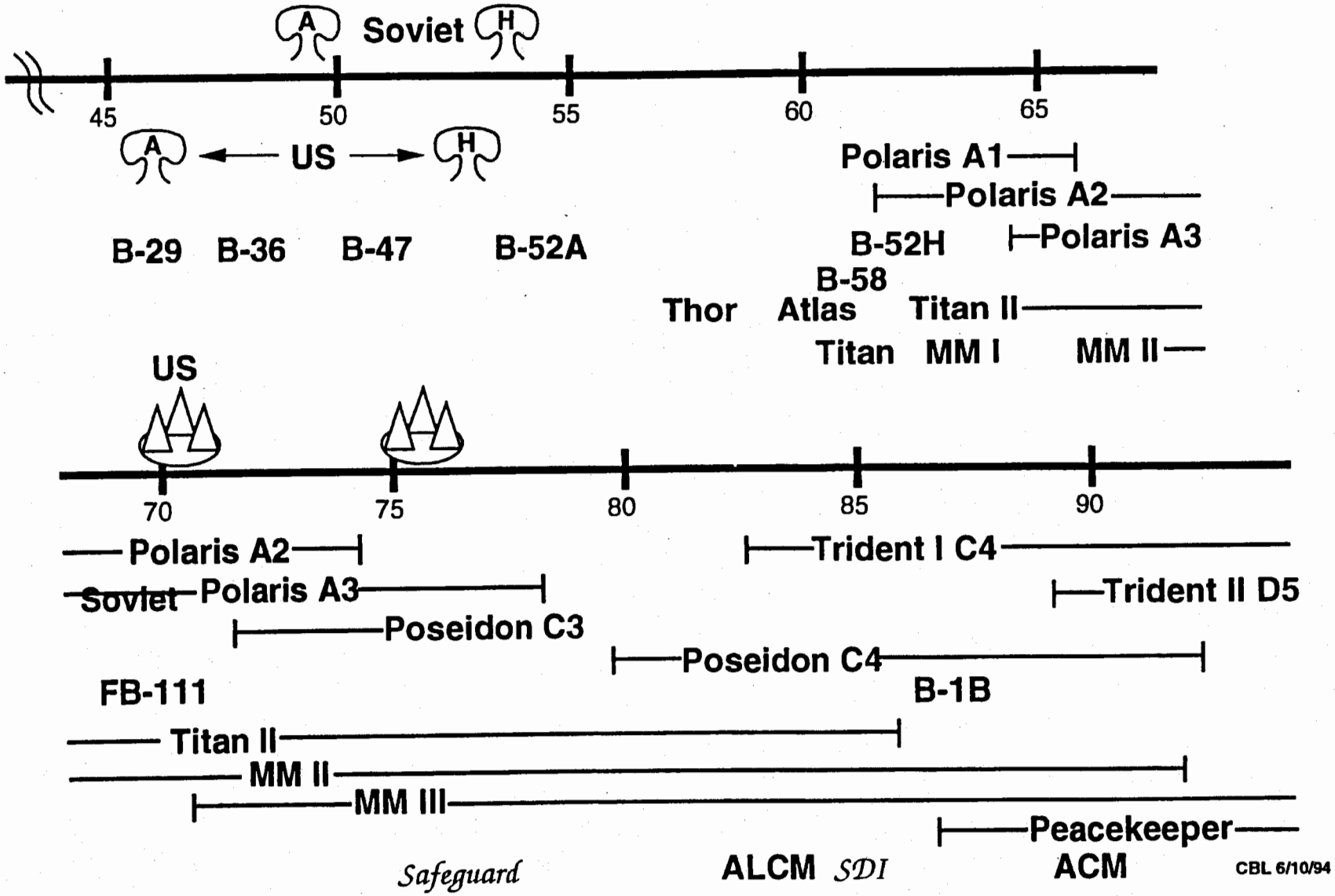
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MC4033 SINGLE CHANNEL

Strategic Delivery Systems



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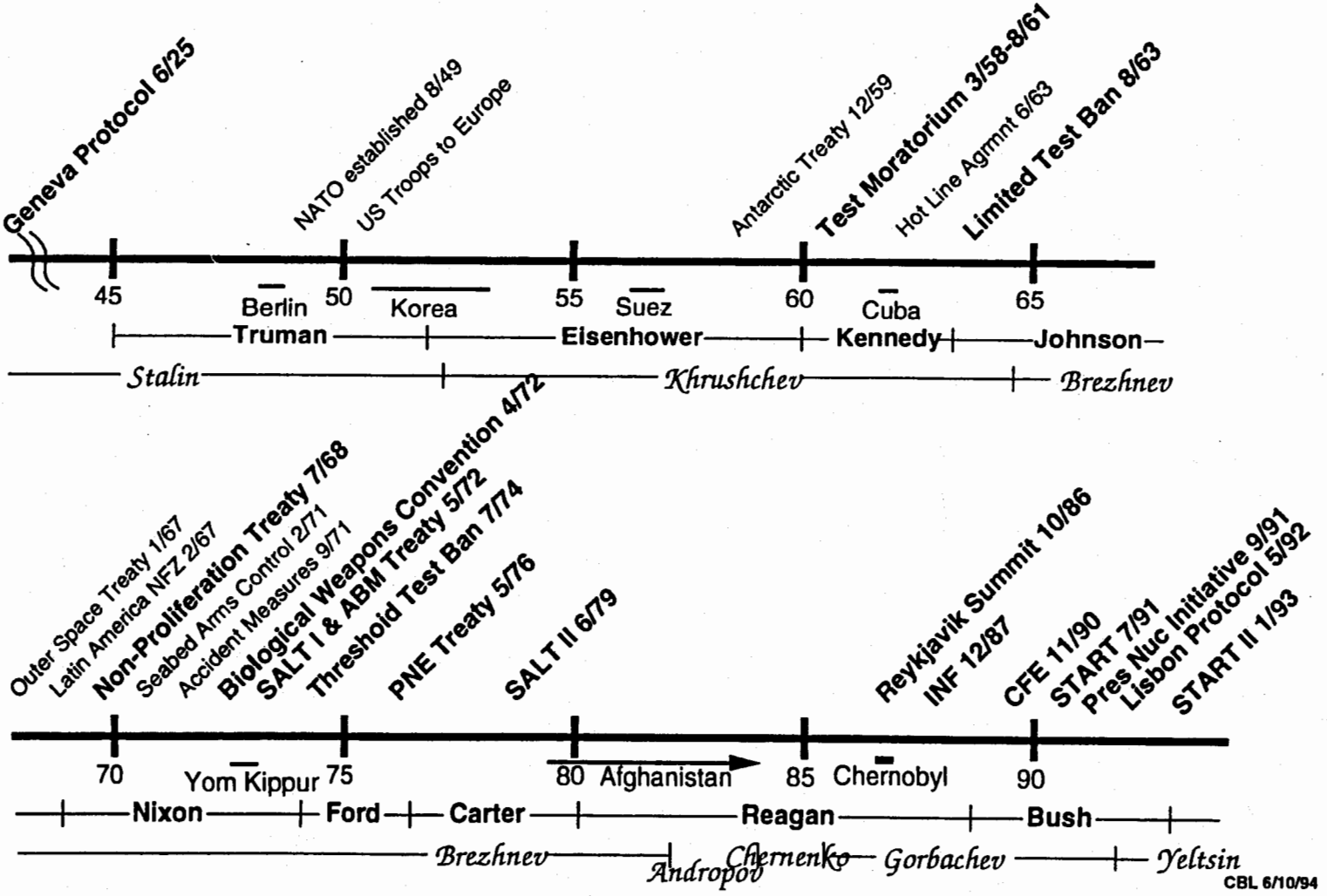
The Evolution of Response Time

1948	Berlin blockade	2 days to assemble
1957	Suez	few hours to launch
1959	DEFCON established	
1960	JSTPS & SIOP	1/3 of bombers ready for immediate take-off
1962	Cuban missile crisis	1/8 on airborne alert

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Arms Control Treaties



CBL 6/10/94

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The Geneva Protocol - 1925

Banned the use in war of asphyxiating, poisonous, or other gases and of bacteriological methods of warfare

US ratified in 1975

All major states now parties

UN Conference on Disarmament is working toward a ban on production and stockpiling

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Test Moratorium - 1958 to 1961

In March 1958, Soviets declared moratorium

In October, negotiations on CTBT began & Eisenhower announced 1-yr U. S. moratorium

May 1960 U-2 incident scrubbed planned summit

Kennedy Administration resumed talks

August 1961, citing French test, Soviets resumed testing

Soviets conducted over 50 tests in the last 3 months of 1961

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The Limited Test Ban Treaty - 1963

Limited nuclear tests to underground

Original signatories were US, Soviet Union, and UK

US ratified 10/63

More than 100 parties now

France ceased above ground tests in 1974,
China in 1980

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The Nonproliferation Treaty - 1968

Eisenhower proposed "Atoms for Peace" in 1953

IAEA established in 1957 to promote and monitor

Nuclear Nonproliferation Treaty was negotiated from 1965 and signed in 1968

NPT Review Conferences every 5 years

After 25 years (1995) a majority vote will determine indefinite or another fixed extension

In exchange for peaceful use of atomic energy, signatories agree to safeguards

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Biological and Toxin Weapons Convention

Outlaws development, production, stockpiling of all biological or toxin weapons and requires destruction of existing stocks

No specific verification provisions

Signed in 1972 and ratified by the US in 1975

Nixon ended US program in 1969 and destroyed stocks

Soviet incident at Sverdlovsk in 1979

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SALT I - 1972

Interim Agreement on Strategic Offensive Arms

Limited launchers (silos and sub tubes) to the then current number

US - 1710 SU - 2347

Limit on heavy launchers (SS-9 and later SS-18)

Five year duration

US ratified in Oct 1972

Reagan repudiated SALT I and II in May 1986

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ABM Treaty - 1972

Johnson and McNamara tried to convince Kosygin at Glassboro to limit ABM systems - June 1967

US announced Sentinel program in September1967

ABM talks were postponed by Soviet invasion of Czechoslovakia in 1968

Nixon changed concept to Safeguard, protecting ICBMs and Washington, DC

Treaty prevents defense of territory, limits to 2 sites with 100 interceptors, limits LPARS

Forbids mobile ABMS or sea, air, or space systems

OPP, Krasnoyarsk, SCC, capabilities questions

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Threshold Test Ban Treaty - 1974

Signatories are the US, Soviet Union, and UK

Limits nuclear tests to 150kT

Verification by NTM (seismic)

A two page treaty

Joint Verification Experiment in 1988

US ratified in 1989

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Peaceful Nuclear Explosives Treaty - 1976

Limited peaceful nuclear explosives to 150kT

Permitted maximum aggregate yield of 1.5 MT, with on site monitoring for yields above 150kT

Plugged a loophole in the TTBT

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START Treaty - 1991

Signed July 31, 1991, 5 months before the end of SU

Lisbon Protocol, signed May 1992, committed Russia, Ukraine, Belarus, and Kazakhstan to START (and NPT)

START limits SNDVs and deployed warheads:

	START	US forces*	Soviet forces*
SNDVs	1600	2246	2500
ICBM & SLBM Warheads	4900	8210	9416
Total Warheads	6000	10563	10271
Heavy ICBM Warheads	1540	------	3080
Mobile ICBM Warheads	1100	------	618
Throw-wt ICs & SLs (metric tons)	3600	2631	6626

*as of 9/90

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The President's Nuclear Initiative-1991

Sept 1991

- Eliminate ground launched tactical nuclear weapons
  - Lance and AFAPs
- Withdraw tactical nuclear weapons from surface ships, subs and P-3 bases
  - B-57, SLCM, B-61
- Stand down strategic bombers from alert
- Stand down MMII
- Cancel mobility for PK and SICBM
- Cancel SRAM II
- Propose joint elimination of MIRVed ICBMs

Jan 1992

- Build only 20 B-2s
- Cancel SICBM
- Halt production of ACM
- Halt production of W88 for Trident II

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START II - 1993

Treaty between the Russian Federation and US, signed by Bush and Yeltsin January 3, 1993, codifed agreements of the Washington summit of June 17, 1992.

START II builds on START - and requires START

	START	START II Ph1	START II Ph2
Start Warheads	6000	3800-4250	3000-3500
ICBM & SLBM Warheads	4900	no sublimit	no sublimit
MIRVed ICBM Warheads	N/A	1200	0
SLBM Warheads	N/A	2160	1700-1750
Heavy ICBM Warheads	1540	650	0
Mobile ICBM Warheads	1100	1100	1100

Phase one to be complete 7 years after entry-into-force, Phase two by 2003

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Books of interest

The Making of the Atomic Bomb, Richard Rhodes, 1986.
Pulitzer prize winner, follows the scientific discoveries that led to the bomb, particularly good at the personalities involved, finishes with vivid descriptions of Hiroshima and Nagasaki. Excellent and entertaining.

At the Highest Levels, Michael R. Beschloss and StrobeTalbott, 1993.
Intimate details of the end of the Cold War, as seen at the top.

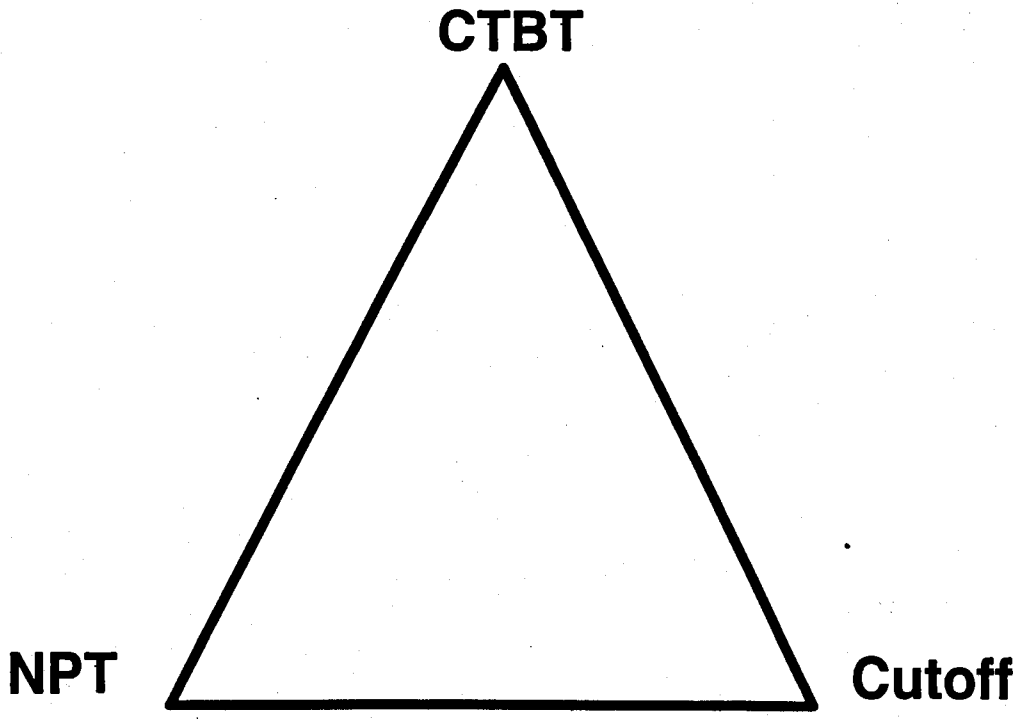
Lenin's Tomb, David Remnick, 1993.
Details the end of the Soviet Union from the viewpoint of the Russian people and their legacy. Choppy, but a very human picture of the great event.

The Wizards of Armageddon, Fred Kaplan, 1983.
Follows the policy and strategy decision regarding nuclear weapons, much emphasis on the early RAND personalities. Very good and readable.

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Nonproliferation Initiative

Alva Myrdahl's Historical View of Nuclear Weapon Controls



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Some Definitions

Proliferation is the spread of weapons of mass destruction (WMD)-- typically nuclear, biological, and chemical weapons--and the systems which deliver them.

Nonproliferation is the use of the full range of political, economic and military tools to prevent proliferation, reverse it diplomatically, or protect our interest against an opponent armed with WMD or missiles.

Counterproliferation measures are the activities of the DoD across the full range of U.S. efforts to combat proliferation.

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Nonproliferation Initiative

What Constitutes a Weapon of Mass Destruction

- Indiscriminate nature of use
- Effect not confined to Belligerents
- Excessive injury -- "cruel and unusual"
- Inability to defend against effectively
- Use would overwhelm medical and evacuation resources
- Notion of "terror"

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ARMS CONTROL IN THE ANCIENT WORLD

1269 BC	Earliest known peace treaty (Egypt and the Hittites), cemented by the marriage of Ramses II to a Hittite princess.
1100 BC	Philistines restrict the use of iron by the Israelites (1 Samuel 13:19-20).
700-800 BC	"...and they shall beat their swords into plowshares..neither shall they make war anymore" (Isaiah 2:2-4).
546 BC	Following the first recorded arms control conference, a "cessation of armaments" ends 72 years of hostilities in the Yangtse River Valley in Honan Province, China.

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ARMS CONTROL IN THE ANCIENT WORLD (CONT'D)

400-500 BC	Athens and Sparta agree to dismantle fortifications although during the negotiations the Athenians hedged their bet by continuing to build their ramparts "high enough to be defended" (Peloponnesian War, Thucydides). Note that, according to the Aristophanes, the women of Athens and Sparta, under the leadership of Lysistrata, tried a different approach to forcing an end to hostilities!
450 BC	Socrates to Glaucon -- no use of poisoned weapons or poisoned water (The Republic, Plato).
300-400 BC	No weapons concealed in wood, no barbed or poisoned points, no points "blazing with fire" (India's Book of Man).
202 BC	After the battle of Zama, Carthage is required to surrender all war elephants and all but 10 triremes to Rome (Book XXX, Livy).

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The Changing Context

Old	New
Bipolar Rigidity	Multipolar Complexity
Predictable	Uncertain
Communism	Nationalism/Religious Extremists
U.S. Dominant Western Power	U.S. Militarily No.1 - Not Economical
Fixed Alliances	Ad Hoc Coalitions
"Good Guys and Bad Guys"	"Grey Guys"
U.N. Paralyzed	U.N. Viable

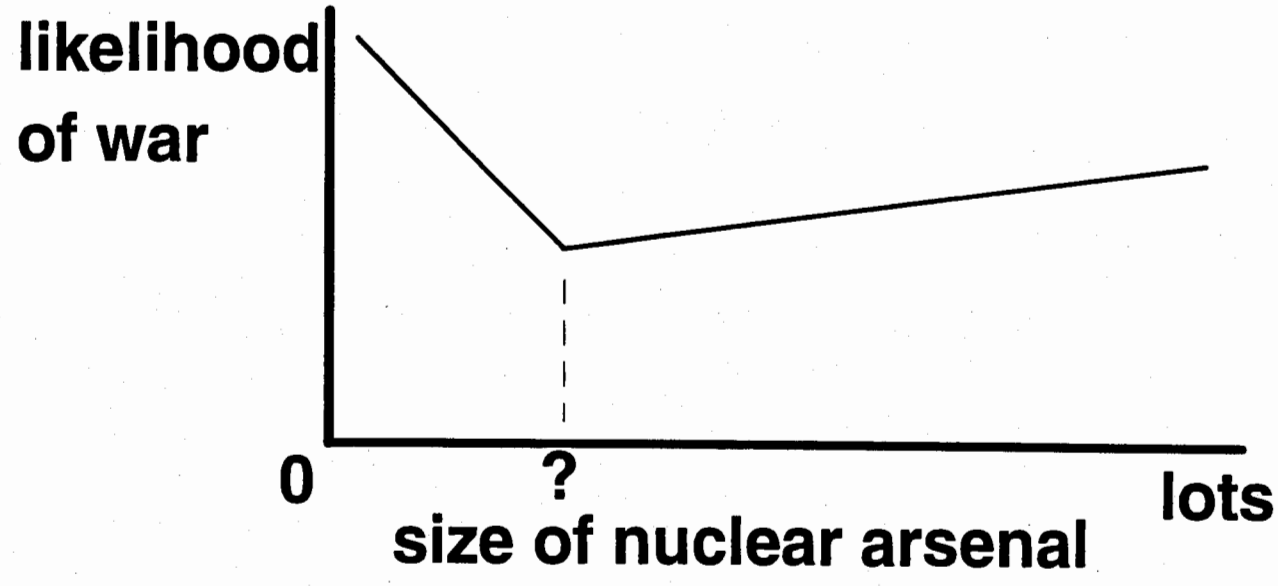
Ref.: National Security in the 1990s: Defining a New Basis for U.S. Military Forces, Rep. Les Aspin, Chrmn House Armed Services Committee, January 6, 1992

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Why Not Zero?

Many nations and individuals want us to completely eliminate weapons -- attractive philosophy but dubious policy:



There may be things worse than nuclear weapons (e.g. biologics)

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There have been some Nonproliferation Successes

-- Sweden abandoned its programs in the 1970s.

-- South Africa stopped its programs in 1992 (6 weapons).

-- Argentina and Brazil renounced their programs.

-- Taiwan and South Korea abandoned their programs in the 1980s.

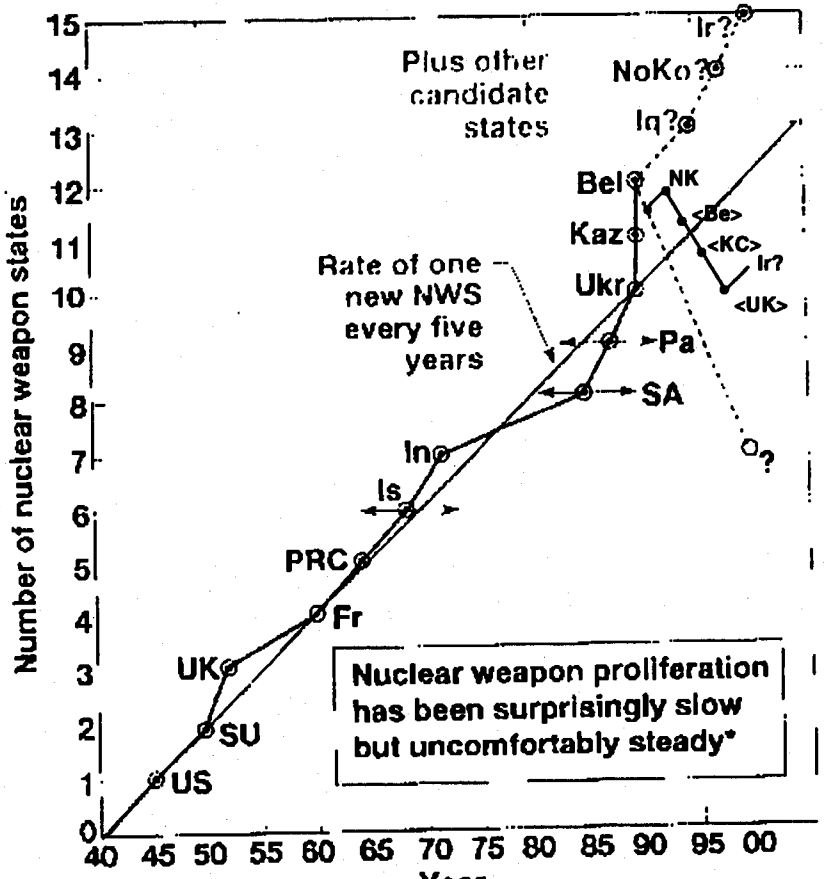
-- Iraq's program "put on hold" by Desert Storm and UN Resolution 687 and 715.

-- Belarus, Kazakhstan, and Ukraine (?) have agreed to return the FSU weapons to Russia.

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How many nuclear weapons states will there be in the year 2000?



*Data from news and journal articles in 1992

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Nuclear Proliferation: A Current Status

- Acknowledged/Declared Nuclear Weapon States
  -- US, UK, China, France, Russia
- Undeclared but widely suspected Nuclear Weapon States
  -- India, Pakistan, Israel
- "Inheritors" of Soviet weapons
  --Ukraine, Kazakhstan, Belarus
- Virtual Nuclear Weapon States (e.g., weapon capabilities but no weapons)
  --Japan, Germany
- Threshold Nuclear Weapon States
  --North Korea
- Aspiring Proliferators
  --Iraq, Iran, Libya, Algeria, various terrorist organizations
- Rollback cases
  --Argentina, Brazil, Sweden, Taiwan, South Africa

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Nonproliferation Initiative

Goals of Proliferation Controls (non → counter)

-- **REMOVE MOTIVATION** FOR POSSESSION OF NUCLEAR WEAPONS

-- **INTERDICT DEVELOPMENT AND ACQUISITION**

-- **DETER EMPLOYMENT** OF KNOWN OR SUSPECTED STOCKPILES OF NUCLEAR WEAPONS

-- **ELIMINATE INFRASTRUCTURE** BY PERSUASION, INTERNATIONAL SANCTIONS (E.G., Res 687)

-- PROACTIVELY **DESTROY FACILITIES** (E.G., Osirak)

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Incorporation of Nonproliferation into US National Security Policy

A successful nonproliferation strategy must address the underlying security concerns that drive the quest to obtain advanced weapons and must encompass contingency planning to deal with these weapons should prevention fail.

National Security Strategy of the United States
August 1991

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Secondary Impacts of Nonproliferation Initiatives

o NPT//NPT Extension Conference (1995):
  -- New and more intrusive inspections regimes
  -- An increased call for transparency
  -- More downward pressure on the stockpile from the "have nots"
  -- Continued pressure against nuclear testing

o Negotiations on controls on fissile materials:
  -- Codify in-place current US and Russian practices
  -- Inspection regimes and transparency
  -- Possible attempts to restrict tritium production

o Export Controls
  -- Heightened concern over "dual use" systems and commodities

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Options across the Nonproliferation -- Counterproliferation Spectrum

disincentives ⟷ **incentives**

venues

Economics — blockades, sanctions — export controls — foreign aid

Politics — political isolation — int'l organizations — alliances

Military Force — war — peacekeeping — military sales — military asst. — covert operations

confrontation ⟷ **cooperation**

COUNTERPROLIFERATION ⟷ **NONPROLIFERATION**

Issues on the Nonproliferation Platter

- Control over the nuclear arsenal of the FSU.
- North Korea
- The 1995 NPT Extension Conference
- China
- The Israeli nuclear arsenal
- The nuclear relationship between India and Pakistan
- Iran

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

[redacted]

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SESSION XVIII

FIELD TRIP TO THE INTER-SERVICE NUCLEAR WEAPONS SCHOOLS' WEAPON DISPLAY AREA

[redacted]

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682

Total pages 682, June 6, 1995
Subject: Survey of Weapon Development and Technology (WR708) (U)

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1 thru 50 S. J. Barnes

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DEPARTMENT OF DEFENSE

NARRATIVE SUMMARIES OF ACCIDENTS
INVOLVING U.S. NUCLEAR WEAPONS
1950-1980

Attached are unclassified summaries describing the circumstances surrounding 32 accidents involving nuclear weapons. Also attached is the Department of Defense (DOD)/Department of Energy (DOE) definition of "accident" used in researching this project.

Twenty-six of these summaries were first released by the Air Force in 1977; another was prepared following the Titan II explosion in Arkansas in September 1980. Those previously-released summaries are marked with a figure "1"; in some cases they include new material made available as a result of more recent research.*

There never has been even a partial inadvertant U.S. nuclear detonation despite the very severe stresses imposed upon the weapons involved in these accidents. All "detonations" reported in the summaries involved conventional high explosives (HE) only. Only two accidents, those at Palomares and Thule, resulted in a widespread dispersal of nuclear materials.

Nuclear weapons are never carried on training flights. Most of the aircraft accidents represented here occurred during logistic/ferry missions or airborne alert flights by Strategic Air Command (SAC) aircraft. Airborne alert was terminated in 1968 because of:

-- Accidents, particularly those at Palomares and Thule,

-- The rising cost of maintaining a portion of the SAC bomber force constantly on airborne alert, and,

-- The advent of a responsive and survivable intercontinental ballistic missile force which relieved the manned bomber force of a part of its more time-sensitive responsibilities. (A portion of the SAC force remains on nuclear ground alert.)

Since the location of a nuclear weapon is classified defense information, it is Department of Defense policy normally neither to confirm nor deny the presence of nuclear weapons at any specific place. In the case of an accident involving nuclear weapons, their presence may or may not be divulged at the time depending upon the possibility of public hazard or alarm. Therefore, in some of the events summarized here, the fact of the presence of nuclear weapons or materials may not have been confirmed at the time. Furthermore, due to diplomatic considerations, it is not possible to specify the location of the accidents that occurred overseas, except for Palomares and Thule.

Most of the weapon systems involved in these accidents are no longer in the active inventory. Those include the B-29, B-36, B-47, B-50, B-58, C-124, F-100 and P-5M aircraft, and the Minuteman I missile.

DEFINITION OF AN ACCIDENT

An "accident involving nuclear weapons" is defined as

-An unexpected event involving nuclear weapons or nuclear weapons components that results in any of the following:

--Accidental or unauthorized launching, firing, or use, by U.S. forces or supported allied forces, of a nuclear-capable weapon system which could create the risk of an outbreak of war.

--Nuclear detonation.

--Non-nuclear detonation or burning of a nuclear weapon or radioactive weapon component, including a fully assembled nuclear weapon, an unassembled nuclear weapon, or a radioactive nuclear weapon component.

--Radioactive contamination.

--Seizure, theft, or loss of a nuclear weapon or radioactive nuclear weapon component, including jettisoning.

--Public hazard, actual or implied.

Narrative Summaries of Accidents Involving U.S. Nuclear Weapons 1950-1980

February 13, 1950/ B-36 / Pacific Ocean, off Coast of British Columbia

The B-36 was enroute from Eielson AFB, Alaska to Carswell AFB, Texas on a simulated combat profile mission. The weapon aboard the aircraft had a dummy capsule installed. After six hours of flight, the aircraft developed serious mechanical difficulties, making it necessary to shut down three engines. The aircraft was at 12,000 feet altitude. Icing conditions complicated the emergency and level flight could not be maintained. The aircraft headed out over the Pacific Ocean and dropped the weapon from 8,000 feet. A bright flash occurred on impact, followed by a sound and shock wave. Only the weapon's high explosive material detonated. The aircraft was then flown over Princess Royal Island where the crew bailed out. The aircraft wreckage was later found on Vancouver Island.

April 11, 1950 / B-29 / Manzano Base, New Mexico

Aircraft departed Kirtland AFB at 9:38 p.m. and crashed into a mountain on Manzano Base approximately three minutes later killing the crew. Detonators were installed in the bomb on board the aircraft. The bomb case was demolished and some high explosive (HE) material burned in the gasoline fire. Other pieces of unburned HE were scattered throughout the wreckage. Four spare detonators in their carrying case were recovered undamaged. There were no contamination or recovery problems. The recovered components of the weapon were returned to the Atomic Energy Commission. Both the weapon and the capsule of the nuclear material were on board the aircraft but the capsule was not inserted for safety reasons. A nuclear detonation was not possible.

July 13, 1950 / B-50 / Lebanon, Ohio

The B-50 was on a training mission from Biggs AFB, Texas. The aircraft was flying at 7,000 feet on a clear day. Aircraft nosed down and flew into the ground killing four officers and twelve airmen. The high explosive portion of the weapon aboard detonated on impact. There was no nuclear capsule aboard the aircraft.

August 5, 1950 / B-29 /Fairfield Suisun-AFB, California

A B-29 carrying a weapon, but no capsule, experienced two runaway propellers and landing gear retraction difficulties on takeoff from Fairfield-Suisun AFB (now Travis AFB). The aircraft attempted an emergency landing and crashed and burned. The fire was fought for 12-15 minutes before the weapon's high explosive material detonated. Nineteen crew members and rescue personnel were killed in the crash and/or the resulting detonation, including General Travis.

November 10, 1950 / B-50 / Over Water, outside United States

Because of an in-flight aircraft emergency, a weapon containing no capsule of nuclear material was jettisoned over water from an altitude of 10,500 feet. A high-explosive detonation was observed.

March 10, 1956 / B-47 / Mediterranean Sea

The aircraft was one of a flight of four scheduled for non-stop deployment from MacDill AFB to an overseas air base. Take-off from MacDill and first refueling were normal. The second refueling point was over the Mediterranean Sea. In preparation for this, the flight penetrated solid cloud formation to descend to the refueling level of 14,000 feet. Base of the clouds was 14,500 feet and visibility was poor. The aircraft, carrying two nuclear capsules in carrying cases, never made contact with the tanker.

An Extensive search failed to locate any traces of the missing aircraft or crew. No weapons were aboard the aircraft, only two capsules of nuclear weapons material in carrying cases. A nuclear detonation was not possible.

July 27, 1956 / B-47 / Overseas Base

A B-47 aircraft with no weapons aboard was on a routine training mission making a touch and go landing when the aircraft suddenly went out of control and slid off the runway, crashing into a storage igloo containing several nuclear weapons. The bombs did not burn or detonate. There were no contamination or cleanup problems. The damaged weapons and components were returned to the Atomic Energy Commission. The weapons that were involved were in storage configuration. No capsules of nuclear materials were in the weapons or present in the building.

May 22, 1967 / B-36 / Kirtland AFB, New Mexico

The aircraft was ferrying a weapon from Biggs AFB, Texas, to Kirtland AFB. At 11:50 a.m. MST, while approaching Kirtland at an altitude of 1,700 feet, the weapon dropped from the bomb bay taking the bomb bay doors with it. Weapon parachutes were deployed but apparently did not fully retard the fall because of the low altitude. The impact point was approximately 4.5 miles south of the Kirtland control tower and .3 miles west of the Sandia Base reservation. The high explosive material detonated, completely destroying the weapon and making a crater approximately 25 feet in diameter and 12 feet deep. Fragments and debris were scattered as far as one mile from the impact point. The release mechanism locking pin was being removed at the time of release. (It was standard procedure at that time that the locking pin be removed during takeoff and landing to allow for emergency jettison of the weapon if necessary.) Recovery and cleanup operations were conducted by Filed Command, Armed Forces Special Weapons Project. Radiological survey of the area disclosed no radioactivity beyond the lip of the crater at which pint the level was 0.5 millirocntgens. There were no health or safety problems. Both the weapon and capsule were on board the aircraft but the capsule was not inserted for safety reasons. A nuclear detonation was no possible.

July 28, 1957 / C-124 / Atlantic Ocean

Two weapons were jettisoned from a C-124 aircraft on July 28 off the east coast of the United States. There were three weapons and one nuclear capsule aboard the aircraft at the time. Nuclear components were not installed in the weapons. The C-124 aircraft was enroute from Dover AFB, Delaware when a loss of power from number one and two engines was experienced. Maximum power was applied to the remaining engines; however, level flight could not be maintained. At this point, the decision was made to jettison cargo in the interest of safety of the aircraft and crew. The first weapon was jettisoned at 4,500 feet altitude. The second weapon was jettisoned at approximately 2,500 feet altitude. No detonation occurred from either weapon. Both weapons are presumed to have been damaged from impact with the ocean surface. Both weapons are presume to have submerged almost instantly. The ocean varies in depth in the area of the jettisonings. The C-124 landed at an airfield in the vicinity of Atlantic City, New Jersey, with the remaining weapon and the nuclear capsule aboard. A search for the weapons or debris had negative results.

October 11, 1957 / B-47 / Homestead AFB, Florida

The B-47 departed Homestead AFB shortly after midnight on a deployment mission. Shortly after liftoff one of the aircraft's outrigger tires exploded. The aircraft crashed in an uninhabited area approximately 3,800 feet from the end of the runway. The aircraft was carrying one weapon in ferry configuration in the bomb bay and one nuclear capsule in a carrying case in the crew compartment. The weapon was enveloped in flames which burned and smoldered for approximately four hours after which time it was cooled with water. Two low order high explosive detonations occurred during the burning. The nuclear capsule and its carrying case were recovered intact and only slightly damaged by heat. Approximately one-half of the weapon remained. All major components were damaged but were identifiable and accounted for.

January 31, 1958 / B-47 / Overseas Base

A B-47 with one weapon in strike configuration was making a simulated takeoff during an exercise alert. When the aircraft reached approximately 30 knots on the runway, the left rear wheel casting failed. The tail struck the runway and a fuel tank ruptured. The aircraft caught fire and burned for seven hours. Firemen fought the fire for the allotted ten minutes fire fighting time for high explosive contents of that weapon, then evacuated the area. The high explosive did not detonate, but there was some contamination in the immediate area of the crash. After the wreckage and the asphalt beneath it were removed and the runway washed down, no contamination was detected. One fire truck and one fireman's clothing showed slight alpha contamination until washed. Following the accident, exercise alerts were temporarily suspended and B-47 wheels were checked for defects.

February 5, 1958 / B-47 / Savannah River, Georgia

The B-47 was on a simulated combat mission that originated at Homestead AFB, Florida. While near Savannah, Georgia, the B-47 had a mid-air collision at 3:30 a.m. with an F-86 aircraft.. Following the collision the B-47 attempted three times to land at Hunter AFB, Georgia, with a weapon aboard. Because of the condition of the aircraft, its airspeed could not be reduced enough to insure a safe landing. Therefore, the decision was made to jettison the weapon rather than expose Hunter AFB to the possibility of a high explosive detonation. A nuclear detonation was not possible since the nuclear capsule was not aboard the aircraft. The weapon was jettisoned into the water several miles from the mouth of the Savannah River (Georgia) in Wassaw Sound off Tybee Beach. The precise weapon impact point is unknown. The weapon was dropped form an altitude of approximated 7,200 feet at an aircraft speed of 180-190 knots. Not detonation occurred. After jettison the B-47 landed safely. A three square mile area was searched using a ship with divers and underwater demolition team technicians using Galvanic drag and hand-held sonar devices. The weapon was not found. The search was terminated April 16, 1958. The weapon was considered to be irretrievably lost.

March 11, 1958 / B-47 / Florence, South Carolina

On March 11, 1958 at 3:53 p.m. EST, a B-47E departed Hunter AFB, Georgia as number three aircraft in a flight of four enroute to an overseas base. After level off at 15,000 feet, the aircraft accidentally jettisoned an unarmed nuclear weapon which impacted in a sparsely populated area 6 1/2 miles east of Florence, South Carolina. The bomb's high explosive material exploded on impact. The detonation caused property damage and several injuries on the ground. The aircraft returned to base without further incident. No capsule of nuclear materials was aboard the B-47 or installed in the weapon.

November 4, 1958 / B-47 / Dyess AFB, Texas

A B-47 caught fire on take-off. Three crew members successfully ejected; one was killed when the aircraft crashed from an altitude of 1,500 feet. One nuclear weapon was on board when the aircraft crashed. The resultant detonation of the high explosive made a crater 35 feet in diameter and six feet deep. Nuclear materials were recovered near the crash site.

November 26, 1958 / B-47 / Chennault AFB, Louisiana

A B-47 caught fire on the ground. The single nuclear weapon on board was destroyed by the fire. Contamination was limited to the immediate vicinity of the weapon residue within the aircraft wreckage.

January 18. 1959 / F-100 / Pacific Base

The aircraft was parked on a revetted hardstand in ground alert configuration. The external load consisted of a weapon on the left intermediate station and three fuel tanks (both inboard stations and the right intermediate station). When the starter button was depressed during a practice alert, an explosion and fire occurred when the external fuel tanks inadvertently jettisoned. Fire trucks at the scene put out the fire in about seven minutes. The capsule was not in the vicinity of the aircraft and was not involved in the accident. There were no contamination or cleanup problems.

July 6, 1959 / C-124 / Barksdale AFB, Louisiana

A C-124 on a nuclear logistics movement mission crashed on take-off. The aircraft was destroyed by fire which also destroyed one weapon. No nuclear or high explosive detonation occurred - safety devices functioned as designed. Limited contamination was present over a very small area immediately below the destroyed weapon. This contamination did not hamper rescue or fire fighting operations.

September 25, 1959 / P-5M / Pacific Ocean, off Washington-Oregon Coast

A U.S. Navy P-5M aircraft, assigned to NAS Whidbey Island, Washington, crashed in the Pacific Ocean about 100 miles west of the Washington-Oregon border. It was carrying an unarmed unclear antisubmarine weapon containing no nuclear material. The weapon was not recovered.

October 15, 1959 / B-52 / KC-135 / Hardinsberg, Kentucky

The B-52 departed Columbus Air Force Base, Mississippi at 2:30 p.m. CST, October 15, 1959. This aircraft assumed the #2 position in a flight of two. The KC-135 departed Columbus Air Force Base at 5:33 p.m. CST as the #2 tanker aircraft in a flight of two scheduled to refuel the B-52's. Rendezvous for refueling was accomplished in the vicinity of Hardinsberg, Kentucky at 32,000 feet. It was night, weather was clear, and there was no turbulence. Shortly after the B-52 began refueling from the KC-135, the two aircraft collided. The instructor pilot and pilot of the B-52 ejected, followed by the electronic warfare officer and the radar navigator. The co--pilot, navigator, instructor navigator, and tail gunner failed to leave the B-52. All four crewmembers in the KC-135 were fatally injured. The B-52's two unarmed nuclear weapons were recovered intact. One had been partially burned but this did not result in the dispersion of any nuclear material or other contamination.

June 7, 1960 / BOMARC / McGuire AFB, New Jersey

A BOMARC air defense missile in ready storage condition (permitting launch in two minutes) was destroyed by explosion and fire after a high pressure helium tank exploded and ruptured the missile's fuel tanks. The warhead was also destroyed by the fire although the high explosive did not detonate. Nuclear safety devices acted as designed. Contamination was restricted to an area immediately beneath the weapon and an adjacent elongated area

January 24, 1961 / B-52 / Goldsboro, North Carolina

During a B-52 airborne alert mission structural failure of the right wing resulted in two weapons separating from the aircraft during aircraft breakup at 2,000 - 10,000 feet altitude. One bomb parachute deployed and the weapon received little impact damage. The other bomb fell free and broke apart upon impact. No explosion occurred. Five of the eight crew members survived. A portion of one weapons, containing uranium, could not b recovered despite excavation in the waterlogged farmland to a depth of 50 feet. The Air Force subsequently purchased an easement requiring permission for anyone to dig there. There is no detectable radiation and no hazard to the area.

March 14, 1961 / B-52 / Yuba City, California

A B-52 experienced failure of the crew compartment pressurization system forcing descent to 10,000 feet altitude. Increased fuel consumption caused fuel exhaustion before rendezvous with a tanker aircraft. The crew bailed out at 10,000 feet except for the aircraft commander who stayed with the aircraft to 4,000 feet steering the plane away from a populated area. The two nuclear weapons on board were torn from the aircraft on ground impact. The high explosive did not detonate. Safety devices worked as designed and there was no nuclear contamination.

November 13, 1963 / Atomic Energy Commission Storage Igloo / Median Base, T

An explosion involving 123,000 pounds of high explosive components of nuclear weapons caused minor injuries to three Atomic Energy Commission employees. There was little contamination from the nuclear components stored elsewhere in the building. The components were from obsolete weapons being disassembled.

January 13, 1964 / B-52 / Cumberland, Maryland

A B-52D was enroute from Westover Air Force Base, Massachusetts, to its home base at Turner Air Force Base, Georgia. The crash occurred approximately 17 miles SW of Cumberland, Maryland. The aircraft was carrying two weapons. Both weapons were in a tactical ferry configuration (no mechanical or electrical connections had been made to the aircraft and the safing switches were in the "SAFE" position). Prior to the crash, the pilot had requested a change of altitude because of severe air turbulence at 29,500 feet. The aircraft was cleared to climb to 33,000 feet. During the climb, the aircraft encountered violent air turbulence and aircraft structural failure subsequently occurred. Of the five aircrew members, only the pilot and co-pilot survived. The gunner and navigator ejected but died of exposure to sub-zero temperatures after successfully reaching the ground. The radar navigator did no eject and died upon aircraft impact. The crash site was an isolated mountainous and wooded area. The site had 14 inches of new snow covering the aircraft wreckage which was scattered over an area of approximately 100 yards square. The weather during the recovery and cleanup operation involved extreme cold and gusty winds. Both weapons remained in the aircraft until it crashed and were relatively intact in the approximate center of the wreckage.

December 5, 1964 / LGM 30B (Minuteman ICBM) / Ellsworth AFB, South Dakota

The LGM 30B Minuteman I missile was on strategic alert at Launch Facility (LF) L-02, Ellsworth AFB, South Dakota. Two airmen were dispatched to the LF to repair the inner zone (IZ) security system. In the midst of their checkout of the IZ system, one retrorocket in the spacer below the Reentry Vehicle (RV) fired, causing the RV to fall about 75 feet to the floor of the silo. When the RV struck the bottom of the silo, the arming and fusing/altitude control subsystem containing the batteries was torn loose, thus removing all sources of power from the RV. The RV structure received considerable damage. All safety devices operated properly in that they did not sense the proper sequence of events to allow arming the warhead. There was no detonation or radioactive contamination.

December 8, 1964 / B-58 / Bunker Hill (Now Grissom) AFB, Indiana

SAC aircraft were taxiing during an exercise alert. As one B-58 reached a position directly behind the aircraft on the runway ahead of it, the aircraft ahead brought advanced power. As a result of the combination of the jet blast from the aircraft ahead, the icy runway surface conditions, and the power applied to the aircraft while attempting to turn onto the runway, control was lost and the aircraft slid off the left hand side of the taxiway. The left main landing gear passed over a flush mounted taxiway light fixture and 10 feet further along in its travel, grazed the left edge of a concrete light base. The feet further, the left main landing gear struck a concrete electrical manhole box, and the aircraft caught on fire. When the aircraft came to rest, all three crew members aboard began abandoning the aircraft. The aircraft commander and defensive systems operator egressed with minor injuries. The navigator ejected in his escape capsule, which impacted 548 feet from the aircraft. He did not survive. Portions of the five nuclear weapons on-board burned; contamination was limited to the immediate area of the crash and subsequently removed.

October 11, 1965 / C-124 / Wright-Patterson AFB, Ohio

The aircraft was being refueled in preparation for a routine logistics mission when a fire occurred at the aft end of the refueling trailer. The fuselage of the aircraft, containing only components of nuclear weapons and a dummy training unit, was destroyed by the fire. There were no casualties. The resultant radiation hazard was minimal. Minor contamination was found on the aircraft, cargo and clothing of explosive ordnance disposal and fire fighting personnel, and was removed by normal cleaning.

December 5, 1965 / A-4 / At Sea, Pacific

An A-4 aircraft loaded with one nuclear weapon rolled off the elevator of a U.S. aircraft carrier and fell into the sea. The pilot, aircraft, and weapon were lost. The incident occurred more that 500 miles from land.

January 17, 1966 / B-52 / KC-135 / Palomares, Spain

The B-52 and the KC-135 collided during a routine high altitude air refueling operation. Both aircraft crashed near Palomares, Spain. Four of the eleven crewmembers survived. The B-52 carried four nuclear weapons. One was recovered on the ground, and one was recovered from the sea, on April 7, after extensive search and recovery operations. Two of the weapons' high explosive materials exploded on impact with the ground, releasing some radioactive materials. Approximately 1400 tons of slightly contaminated soil and vegetation were removed to the United States for storage at an approved site. Representatives of the Spanish government monitored the cleanup operation.

January 21, 1968 / B-52 / Thule, Greenland

A B-52 from Plattsburgh AFB, New York, crashed and burned some seven miles southwest of the runway at Thule AB, Greenland while approaching the base to land. Six of the seven crewmembers survived. The bomber carried four nuclear weapons, all of which were destroyed by fire. Some radioactive contamination occurred in the area of the crash, which was on the sea ice. Some 237,000 cubic feet of contaminated ice, snow and water, with crash debris, were removed to an approved storage site in the United States over the course of a four-month operation. Although an unknown amount of contamination was dispersed by the crash, environmental sampling showed normal readings in the area after the cleanup was completed. Representatives of the Danish government monitored the cleanup operations.

Spring 1968 / At Sea, Atlantic

Details remain classified.

September 19, 1980 / Titan II ICBM / Damascus, Arkansas

During routine maintenance in a Titan II silo, an Air Force repairman dropped a heavy wrench socket, which rolled off a work platform and fell toward the bottom of the silo. The socket bounced and struck the missile, causing a leak from a pressurized fuel tank. The missile complex and the surrounding area were evacuated and a team of specialists was called in from Little Rock Air Force Base, the missile's main support base. About 8 1/2 hours after the initial puncture, fuel vapors within the silo ignited and exploded. The explosion fatally injured one member of the team. Twenty-one other USAF personnel were injured. The missile's re-entry vehicle, which contained a nuclear warhead, was recovered intact. There was no radioactive contamination.

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United States Department of State
Bureau of Public Affairs

Office of the Historian

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Historical Research Project No. 1421

NUCLEAR ACCIDENTS AT PALOMARES, SPAIN IN 1966 AND THULE, GREENLAND IN 1968

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UNITED STATES DEPARTMENT OF STATE
REVIEW AUTHORITY: FRANK H PEREZ
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~~(S)~~ U.S. nuclear weapon deployments will remain a feature of deterrence in our alliance system for the forseeable future. Deployed weapons are subject to accidents and incidents. It is simply a fact of life. Although every effort is made to reduce the risk of an accident with the deployed stockpile, the simple fact that deployed weapons must be maintained, modernized, trained with, and exercised means that some accident risk remains. ~~B1~~

~~(S)~~ In addition to reducing accident risk to a minimum, we must be prepared to deal with the consequences of an accident should one happen. The Washington interagency group is convinced that the degree of damage to U.S. national security from any future nuclear accident or incident would depend in large measure on the quality of U.S. Government and host ~~B1~~

government management of the emergency. In short, if handled smoothly and effectively, the political costs could be minimized. If managed poorly, negative effects will be magnified.

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(U)Dr. James E. Miller of the Office of the Historian, Department of State, has done an outstanding job of surfacing the diplomatic problems of Palomares and Thule in a paper which is interesting reading. I hope this contribution to our understanding of the kinds of demands which could be made on our embassies is useful but continues to be unused.

Colonel Michael Barrett Seaton
Bureau of Political-Military Affairs
April 1985

SUMMARY

(~~S~~)The January 17, 1966 and January 21, 1968 crashes of nuclear-weapons-equipped SAC B-52 bombers on the territory of two U.S. allies thrust the Embassies in Spain and Denmark into complex and ultimately unsuccessful negotiations to retain rights for SAC overflights and for the storage of nuclear weapons. Other important and interrelated responsibilities assumed by the Embassies included managing a public relations effort designed to influence the citizens of the host state, assisting in efforts to clean up the contaminated crash sites, and settling the damage claims filed by the nationals of the host nation. All of these functions were carried out in cooperation with the Department of Defense. A clear division of responsibility emerged: the military concentrated on clean-up and claims settlement while the Embassy or Department of State assumed primary responsibility for retaining U.S. nuclear weapons rights. In Spain public relations matters constituted the major cause of conflict between the Embassy and military, while geographic separation gave the Department of Defense primary control of public relations in Greenland. The role of the American Ambassador and the depth of Embassy involvement during these crises varied in accordance with the circumstances of the accidents, the form of government of the host nation, and the character of the U.S. chief of mission.

(U)Certain clear lessons emerge from the two accidents. Within the limits imposed by atomic weapons information security, the United States should seek to provide the press with with all available information as quickly as possible. Expert technical assistance should be provided both at the crash site and at the Embassy as soon as possible after an accident. The United States should be ready to provide quick service for claims arising from an accident. The U.S. Ambassador must be in a position to assert his responsibility for all political activities in the host nation.

B1, B3

PALOMARES, SPAIN, JANUARY 1966

The Incident

(U)At approximately 10:22 a.m., January 17, 1966, a KC 135 refueling aircraft operating from Moron AFB collided with a B-52 bomber of the Strategic Air Command in the skies over the southern Spanish village of Palomares. Seven U.S. airmen were killed. The four unarmed nuclear devices which the aircraft was carrying apparently broke lose from their moorings during the disintegration of the B-52. One bomb fell with other wreckage into the sea off Palomares; the other three bombs landed around the village. The non-nuclear charges on two of these devices exploded releasing quantities of plutonium into the air and onto the ground. Wreckage of the two aircraft was strewn over a wide area around the village, but, fortunately no townspeople were injured by the falling debris or by plutonium contamination.

~~(S)~~The U.S. Air Force took full control of on-site efforts to recover the wreckage and nuclear armament and to decontaminate the crash site. The Department of Defense also took charge of the settlement of claims arising from the accident. The U.S. Embassy in Spain initially had an exclusively political role: dealing with the impact of the accident on U.S.-Spanish relations. Subsequently, it moved into areas which initially had been under exclusive control of the Department of Defense: the settlement of claims arising from the accident, and the clean-up operations. The objective of American diplomacy was to retain Spanish defense cooperation even at the cost of modifying existing arrangements for nuclear overflights and accepting damaging restrictions on the release of information concerning Palomares imposed by the Spanish Government.

~~(S)~~The U.S. Embassy at Madrid was informed of the accident at Palomares by phone by its military liaison group within an hour of the crash. In turn it notified the Department of State of the available details of the crash and initial Spanish Government and public reaction. Ambassador Angier Biddle Duke had been attending a meeting of a major business association when an aide arrived to verbally inform him of the accident. He immediately left the meeting and drove to the Spanish Foreign Office to seek a meeting with Foreign Minister Ferdinando Maria Castiella. However, the Foreign Minister was not in his office and Duke reported the available details of the accident to the Under Secretary for Political Affairs,

THULE, GREENLAND, JANUARY 1968

(U)At approximately 3:40 pm, January 21, 1968, a SAC B-52 bomber carrying nuclear weapons crashed on the 7-foot-thick ice of North Star Bay approximately 7 miles from the runway at Thule AFB. The aircraft had been attempting an emergency landing after a fire broke out in its heating system. Six crewmen bailed out successfully and were subsequently rescued. A seventh died during the bailout procedure. The four nuclear devices remained within the aircraft and broke up upon impact. Alpha radiation was released in the crash site area. In addition, small fragments from the aircraft passed through the ice pack and settled at the bottom of North Star Bay.

(U)The B-52 crash occurred at a particularly sensitive time for the government of Danish Prime Minister Jens Otto Krag, since a national election campaign was in its final days. The Danish Government, upon receipt of information of the crash (apparently through military channels), released a statement (January 22, 1968) which claimed that Denmark did not permit flights by nuclear armed aircraft over any part of its national territory, including Greenland, and stressed that the plane had been attempting an emergency landing after encountering inflight problems. The text of this statement was not cleared with the U.S. Government prior to its release. The United States had operated its nuclear armed aircraft over Greenland since the conclusion of a 1957 agreement with the Government of Denmark.[34]

(U)Because the wreckage was located in a remote and lightly populated area, claims did not play a major role in the Thule incident. The distance between the crash site and Denmark reinforced the clear division of responsibility between the military and U.S. Embassy already evident after the Palomares accident. The Department of Defense took charge of the recovery and clean-up operations at the crash site, and assumed responsibility for the payment of claims arising from the accident. In addition, the Defense Department public relations teams took charge of the press covering the recovery operation in Greenland and were the primary source of information for reporters in Washington. However, Denmark's democratic politics put an even greater premium on the skillful handling of public relations by Ambassador Katherine White and the Embassy staff in Copenhagen.

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Adolfo Cortina. In his meetings with Cortina and other senior officials of the Spanish Foreign Office Duke attempted to coordinate aresponse to the accident and expressed U.S. apologies for the incident. Despite the fact that many of the details of the accident were known to both the Spanish and foreign press, Spanish officials requested that the "nuclear aspect" be "played down . . . in any public releases" and that Spain be "disassociated from any nuclear implications." Ambassador Duke instructed all U.S. agencies in Spain to follow the press guidance set out in a March 1964 "USAFE nuclear accident information plan" and withheld authorization for any public reference to the B-52's nuclear armament.[1] An initial press statement which did not mention the nuclear aspects of the accident was cleared with the Government of Spain and released at Torrejon AFB at 9:45 p.m. local time on January 17.

Initial Public Relations

(U)From the start of the Palomares recovery operation, the Embassy faced two interconnected public relations problems: 1) insuring accurate reporting in the media and 2) winning the agreement of Spanish authorities to provide as complete information on the operation as security considerations permitted. Without access to more information, the tendency of the press toward misrepresentation and sensationalism increased. The Franco regime, however, in spite of a certain mellowing of its authoritarian nature after a quarter century in power, saw the press as an adversary to be fended off rather than placated.

(~~S~~)From the beginning, Department of State officials wanted to deal publicly with the nuclear issue. The Spanish Government, however, strenuously objected to providing any details to the press, an attitude initially shared by U.S. military representatives on the scene at Palomares.[2] U.S. officials recognized that holding on to the trust and cooperation of the Franco regime was critical to the successful conclusion of the recovery of the bombs and to maintaining its basing and overflight rights. Thus, the Spanish Government held a veto power over the release of information. In order to maintain Spanish confidence, the Embassy and recovery teams at Palomares made conscious efforts to assure that the Spanish Government was kept fully informed of all apsects of the recovery operation. Ambassador Duke met frequently with Spanish officials, JUSMG kept the High General Staff informed of the Defense Department's actions at Palomares, while Secretary of State Rusk and General Earl Wheeler, the Chairman of the Joint Chiefs of Staff, sent personal messages to their Spanish counterparts thanking them for their cooperation and

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~~B1, B3~~

assuring them that the recovery operation was receiving constant attention at the highest levels of the U.S. Government.[3]

~~(S)~~ The Franco regime's efforts to avoid mention of the B-52's nuclear armament collapsed on January 19 when United Press International reported not only that the B-52 was carrying nuclear bombs but that one was missing and hundreds of geiger counter equipped U.S. troops were combing the countryside around Palomares searching for signs of radioactivity. On January 20, the Spanish Government authorized release of a statement which admitted the B-52 carried nuclear armament but insisted that initial radiological surveys had established that no public health danger existed in the Palomares area. The statement represented a Spanish redrafting of an Embassy-proposed press release which provided fuller details of the nuclear aspects of the accident.[4] By January 21 the nuclear contamination issue was receiving full play in the Spanish press. The failure of the U.S. and Spanish Governments to provide accurate information on the crash combined with the problem of the missing nuclear weapon created serious public relations problems for the Embassy for months afterwards.

(S)The concern of Spanish officials with the public relations aspects increased as the size of the foreign press corps covering the accident grew. In an effort to impose censorship on the Spanish public, the Franco Government banned the sale of foreign newspapers and news magazines. On January 21, the Spanish Foreign Office called in Duke to complain about an alarmist American wireservice story which attributed its sources to the U.S. Embassy. Franco had read the article and was upset. The Spanish Government threatened to take unspecified "independent action," in retaliation for the leak. Duke was able to refute that story's attribution to U.S. sources by contacting the UPI bureau chief in Madrid and thus to preserve close intergovernmental ccoperation.[5]

~~(S)~~The key motivations for the Franco Government's sensitivity were its concern about the impact which stories about nuclear contamination would have on southern Spain's lucrative tourist industry and its fears that the underground and semi-legal opposition forces, including the outlawed Communist Party, would effectively exploit the incident in their campaign to topple the regime. Ironically, the sensationalism of the Communist-controlled and clandestine "Independent Spanish Radio" would have considerable effect on the populace of Palomares precisely because the information provided by their own government was both sketchy and believed unreliable. U.S. officials also suspected that the Government of Spain intended to use the bomb accident as a bargaining chip

in the next round of base negotiations scheduled for 1968.[6] B1, B3

(S) For U.S. officials, the critical issue was limiting adverse publicity which could trigger a formal Spanish demand for the cessation of overflights of its territory by nuclear armed aircraft. The threat that such permission would be withdrawn first surfaced on January 19 when Spanish Vice President Munoz Grandes suggested that in future the United States conduct its refueling operations over international waters. Officials at the Spanish Foreign Office also complained to Embassy officials about holding refueling operations over their territory. Duke warned Washington that the speedy recovery of the missing fourth nuclear device was the key to reducing press coverage which could force the Spanish Government to suspend overflight permission. Continued intense press coverage would force the Spanish Government to take dramatic action to reassure restive domestic public opinion.[7]

(S) Duke's warning proved instantly prophetic. On January 22 Munoz Grandes met with the Chief of the U.S. JUSMG, Major General Stanley J. Donovan, to request the suspension of the overflight of Spanish territory by nuclear-armed U.S. aircraft. The Spanish Foreign Office initially told reporters that any changes in the flight paths of its aircraft were unilaterally made by U.S. authorities. However, in the face of continued intense press coverage of Palomares and rising discontent among influential segments of the Spanish intelligentsia and bureaucracy, Spanish Information Minister M. Fraga Iribarne told a January 29 press conference that U.S. nuclear armed overflights of Spain had been "permanently" suspended, adding that all U.S. medium bombers were being withdrawn from Torrejon AFB and that no nuclear armaments were stored on that base. Fraga did not hold any consultations with U.S. officials prior to making this statement.[8] B1, B3

The Question of a Joint Statement

(S) The United States, following its established policy, refrained from public comment on issues relating to its nuclear defense operations. The Embassy, however, was actively attempting to counter misinformation originating from the recovery site. Because of the isolated location of the recovery operation, security measures enforced by the government, and the limited value of news relating to the land clean-up operation, the majority of the foreign press covering the Palomares story stayed in Madrid, awaiting fresh developments in the recovery operations. All of these conditions produced misinformation and sensationalism.

The Embassy was also concerned about the lack of information being provided by the Department of Defense's on site press-spokesman. The paucity of factual information provided correspondents visiting the scene tended to exacerbate already unfavorable reporting. In an effort to counter these factors, Ambassador Duke toured the recovery site on February 3 and upon his return to Madrid held a news conference at which he explained the progress of the clean-up operation as well as the technical difficulties facing the Navy in its search for the missing bomb. Duke's continued concern over accurate press coverage of the clean-up and salvage operations led him to strongly endorse a suggestion by the DOD press representative at the crash site for a press conference, jointly sponsored by the Embassy and Spanish government, and preferably held at Palomares, which would dispell rumors about contamination. The Spanish Government did not act upon this suggestion due to internal disagreements. After State Department-DOD consultations the idea was vetoed as "undesirable" by the U.S. Government.[9]

(~~C~~) Inaccurate reporting dogged U.S. officials. The day after Duke's February 3 press conference, the New York Times erroneously quoted him as identifying the missing bomb as an hydrogen device. In view of Spanish sensitivity to any discussion of the bomb's characteristics (particularly its killing power and radius), Duke obtained a retraction from the Times' Spanish correspondent, Tad Szulc.[10]

(~~S~~) Meanwhile the Embassy continued to press the Spanish Government for the release of a joint statement which would clarify the details of the Palomares accident and clean-up. In mid-February 1966, the Embassy submitted to the Foreign Office, the Spanish Atomic Energy Commission (JEN), and Vice President Munoz Grandes a State Department draft of a joint U.S.-Spanish statement. While initial reaction to the U.S. proposal was generally favorable, all three forwarded suggestions for changes in the text. An internal Spanish Government debate on the text effectively blocked the issuance of any statement. Vice President Munoz Grandes, in particular, was opposed to any public statement on the accident at a time when the Soviet Union had initiated a major propaganda offensive. He feared that the Soviet Union would simply exploit additional information to keep the issue before world public opinion. Information Minister Fraga and the JEN favored release of the text, while the Ministry of Foreign Affairs was divided on the issue. Finally, Franco vetoed any further disclosures. On February 25, the Embassy suggested that the United States considerd issuing a unilateral statement.[11]

(~~S~~)On March 1, the press impasse was finally broken by the action of the Chairman of the JEN, Jose Maria Otero. Without clearance from either the Foreign Office or High General Staff of the Spanish Army, he discussed the contamination issue, outlined clean up operations, and confirmed that one of the nuclear weapons was still missing in a press interview. U.S. officials speculated that Otero's actions were encouraged by Information Minister Fraga, a leading proponent of openness with the press.[12] The following day, the Department of State released a previously prepared statement stressing the safety features of U.S. nuclear weapons and confirming the details of Otero's interview.

(~~C~~)On March 8 Ambassador Duke, Information Minister Fraga, and members of their families went swimming in the sea off Palomares to demonstrate the safety of the area for tourists. The germ of this idea may have originated with Spanish Desk Officer Frank Ortiz who in January 1966 suggested that "newsworthy" visitors patronize hotels near the crash site. The Spanish Government had scheduled a new hotel for opening in March at Mojacar close by Palomares and was very concerned that the adverse publicity would destroy the tourist season in that area. Duke conceived the idea of attending the opening and taking a swim. Joined by most of his staff, he took the plunge into the icy waters in the morning. Later that afternoon, Fraga and Duke took a second swim. The impact on world public opinion was immediate and highly favorable. This vivid proof that the sea was not endangered by contamination probably saved the tourist season in Southern Spain.[13]

(~~C~~)As the clean-up operation progressed successfully and local claims procedures began operating effectively, the major public relations problem facing Embassy officials was providing information on the effort to recover the missing nuclear weapon. In view of security considerations and the difficulties of securing Spanish agreement to the release of information, the Embassy secured the concurrance of the Air Force command in Spain for its recommendation that the United States inform the Franco Government that it intended to make appropriate information on recovery operations available to the press without prior consultations.[14]

Location of the Missing Bomb

(~~S~~)After an exhausting search, the missing bomb was finally located and tentatively identified on March 15, 1966. However, the reluctance of the commander on the scene, Rear Admiral William Guest, to release information without definite confirmation that the object was in fact the missing bomb

forced the Embassy to cancel precipitously an early morning press conference on March 16. At the same time, leaks within the military chain of command outside Spain put increasing pressure on the Embassy and military recovery operation to provide some sort of information. Finally, on March 17 after confirmation that the bomb had been located, the Embassy issued a statement which had previously been prepared through consultations with the Department of State. Equipment problems and the loss of contact with the bomb for 9 days delayed final recovery.[15]

(~~S~~)The long search and subsequent recovery problems combined with the scarcity of information available reinforced press tendencies toward sensationalism. At the urging of U.S. representatives in Spain, including Ambassador Duke, the Department of Defense approved a plan to permit representatives of the press to view the bomb shortly after it was hauled aboard a U.S. Navy recovery vessel. The Embassy had apparently initially wanted the press to be present during the recovery operation to establish U.S. credibility but accepted military objections to this plan. As an alternative it suggested that Spanish officials and press pool representatives view the recovered bomb and that the press then receive a formal briefing on the recovery operation.[16]

(~~S~~)During the recovery operation, leaks from the Spanish representative at Palomares created additional press problems and Ambassador Duke sent an Embassy representative to the recovery site to "insure . . . press treatment . . . recovery operations protects and advances U.S. interests," through strict control of the information released. In a largely unsuccessful effort to minimize speculation, the United States had established a daily Navy-Air Force joint briefing at Palomares. However, the long delay in recovery of the missing bomb, the limited information being provided by military officials, isolation of the site, and the attendant growth of rumors defeated this aspect of the public relations effort and spawned sensationalistic accounts, particularly in the Western European press. In addition, the long simmering differences between the Embassy staff and the DOD press representatives at Palomares surfaced when Embassy officers made their unhappiness known to members of the press, complaining that the military treated them as "nuisances."[17]

(U)The Navy's inability to retrieve quickly the lost nuclear weapon after its discovery created additional problems for the Embassy. On the international level the Soviet Union was exploiting U.S. difficulties to attack the stationing of nuclear weapons outside U.S. national territory and demanding international verification of the recovery. Meanwhile a large and growing group of journalists was waiting in Madrid for

permission to visit the crash site and view the results of the recovery operation. Press coverage of the clean up and recovery was limited, first by the need to keep everyone not associated with the operation away from areas of potential contamination at the land sites and then by security considerations and the practical impossibility of accomodating large numbers of press representatives on the recovery ships. The Franco Government, of course, preferrred to keep the press away from the site entirely. Its aims were facilitated by the isolation of Palomares and the slow progress and generally unnewsworthy nature of daily recovery and clean-up operations. The vast majority of the press gladly preferred to await major developments in the comfort of Madrid's hotels.[18]

~~(S)~~ On April 7, 1966, the naval task force retrieved the missing bomb. The Embassy notified the Spanish Foreign Office and Information Ministry while JUSMG reported the succesful recovery to the High General Staff, Air Ministry and JEN. Ambassador Duke proceeded to the recovery site together with representatives of the Spanish Government.[19] On April 8, the Spanish officials boarded a U.S. Navy recovery vessel and viewed the weapon. A small number of press representatives were brought alongside the recovery ship for a glimpse of the bomb and the U.S. military provided a briefing on the recovery operation for the the entire press corps. At the request of the Government of Spain, relayed through the Embassy, the recovery ship with its atomic cargo immediately departed for the United States without docking at any Spanish port. A majority of the press departed soon after the weapon recovery was completed.[20]

~~(S)~~ Palomares remained a public relations problem for the Embassy for nearly a decade afterwards. The annual anniversaries of the accident were marked by television and press retrospectives focusing on the effects of the crash on the people of Palomares. The Embassy was frequently requested to provide technical assistance for these inquiries and to explain the U.S. position. The population of the village declined rapidly as the soil became increasingly alkaline and incapable of supporting the area's primary cash crop, tomatoes. In addition, many villagers departed out of fear of radiation effects. Internal opponents of the Franco regime, initially spearheaded by the Duchess of Medinia-Sidonia, attacked the Spanish Government, claiming it had failed to safeguard the interests of its own citizens, particularly their rights to claim damages from the United States. The Embassy originated a plan to show U.S appreciation to the people of Palomares for the assistance they rendered to the downed aviators and their patience during the subsequent clean up by building a water desalination plant to assist in irrigation

projects. The idea, which Washington approved with some reservations, ran into a series of bureaucratic impasses in Spain.[21]

Conditional Reinstatement of Permission for Overflights

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(~~S~~)Once the Spanish Government suspended overflight permission for SAC nuclear armed bombers, the Embassy, through the JUSMG, was the primary channel through which the United States sought a reinstatement of its former privilege. Initially, the Embassy counseled Washington to avoid bringing up the overflight issue until the fourth atomic device was recovered. Negotiations for basing rights for three U.S. fighter squadrons assigned to NATO (from which Spain was excluded) and the approach of the renegotiation of the U.S.-Spanish Defense Cooperation Agreement further complicated the U.S. position.[22]

(~~S~~)Shortly after the recovery of the missing bomb, the Embassy advised the Department of State that it believed the Spanish Government would agree to permit flights of nuclear equipped-aircraft over the Straits of Gibraltar, but that this concession would increase Spanish resistance to allowing nuclear armed aircraft to overfly its territory,adding that it could not judge "when, if indeed ever, . . . GOS would be willing again . . . expose itself to . . . possibility, however remote, of another Palomares."[23]

(~~S~~)Nevertheless, acting on instructions from the Departments of State and Defense, the chief of JUSMG met with Munoz Grandes on May 3, 1966 to begin a long and ultimately unsuccessful effort to resume SAC flights over Spanish territory. While Munoz Grandes appeared willing to consider permitting U.S. aircraft to cross southern Spain via the base at Rota, strong opposition to any rescinding of the ban on overflights, led by the Spanish Foreign Office, delayed any final action on the U.S. request. Finally, at the end of December 1966, Munoz-Grandes informed the chief of JUSMG that the resumption of overflights by nuclear armed aircraft was "out of the question" for the forseeable future. Munoz Grandes did leave open, subject to further study by the Spanish Government, the possible use of Rota airfield "as (a) stopover."[24]

Settlement of Claims

(~~S~~) Although the Embassy showed no desire to interfere with the on-site operations of the Air Force and Navy it was slowly dragged into a more active role in the Palomares area by the complaints of local residents (magnified through the reporting of the Spanish and international press) that claims settlements were progressing too slowly. Ambassador Duke urged that the process be sped up. On February 12, 1966, at a meeting of the chief of JUSMG and the High General Staff, Spanish officers requested that the claims agreements forms used by the United States be reworded to permit filing later or supplementary claims for 10 to 20 years after the accident. They pointed out that the effects of the crash on the citizens and land of Palomares might not be fully revealed for many years after the accident. The Embassy contacted the Department of State and urged speedy consideration and action on the position of the Spanish Government.[25] Meanwhile, claims processing was suspended at Spanish request. After consideration of the legal aspects of the Spanish request, the Department of State forwarded a letter for delivery to the Spanish Government which explained the procedures outlined in the Foreign Claims Act and provided assurances that claims could be filed for an extended period of time following the accident. Negotiations on the claims settlements issue took place on February 19 and 21, 1966 between the chief of JUSMG and a representative of the Spanish High General Staff. The negotiators reached agreement that the assurances contained in the U.S. letter satisfied Spanish concerns.[26]

(~~C~~) Claims settlements continued for years after the accident. Francisco Simo Orts, the Spanish fisherman who saw the fourth bomb land at sea and assisted in rescuing downed US airmen, filed a series of claims against the United States which embarrassed both U.S. and Spanish officials and kept the issue of U.S. fairness in the press. The Embassy also inherited responsibility for handling claims after the military clean-up teams left Palomares, serving as a clearing house for the inquiries and complaints of the Spanish Government. The satisfaction of claims of Spanish citizens remained an irritant in U.S.-Spanish relations for nearly a decade. In 1976, the Embassy braced for major demonstrations which would mark the tenth anniversary of the Palomares crash. None took place. Internal political matters connected with the transition from dictatorship to democracy in Spain had evidently lessened public interest in the 1966 crash.[27]

Clean-Up Operations

(U)As was the case with claims issues, the Embassy initially left the clean-up operations to the representatives of the Department of Defense at Palomares. However, the requirements of an effective public relations effort and of effective communication with the Spanish Government inevitably led to an increased Embassy role in these matters.

~~(S)~~Initially, Ambassador Duke's major requirement was accurate information on the on-site operations. Teams of nuclear experts from the Department of Defense and the Atomic Energy Commission had arrived at the crash site within days of the accidents and were directing the clean-up and bomb land portion of the search for the missing nuclear bomb. The Embassy lacked a specialist in nuclear matters Duke relied upon his military attaches to provide the Embassy with full information on the recovery and decontamination operations. Utilizing their contacts with the 16th Air Force, the attaches were able to provide the Ambassador with a frequent (initially daily) written report on operations at Palomares which was then summarized and passed on to the State Department.[28]

~~(C)~~In early February the first concern of U.S. officials in Spain was rapid completion of a safe clean-up operation. The thoroughness of the operations carried out to insure the safety of the local population had the paradoxical effect of increasing public concern with the effects of radiation and of keeping the Palomares story in the forefront of news for the Spanish and international press. In addition, the tourist season was approaching. Tourism was a principal element in the rapid expansion of the Spanish economy in the 1960's and a critical factor in the modernization of Spanish politics and society. Both the United States and Spanish Governments were eager to eliminate the memories of Palomares in order to assure the continued growth of this key element in Spain's development. However, accelerating the pace of the decontamination effort proved difficult. On February 2, 1966, General Delmar Wilson, the on-site commander of the clean-up operation signed an agreement with the Spanish on-site representative, General Arturo Montel, which committed the United States to build a disposal pit near Palomares in which all contaminated soil registering 7,000 counts per minute (cpm) on a geiger counter would be stored. U.S. military officials quickly discovered that these ground rules for removal of contaminated soil could not be met by the deadline established by the tourist season. They also concluded that these figures were excessive from the safety standpoint and would seriously

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complicate efforts to remove contaminated materials. Finally, the Embassy and JUSMG opposed the creation of a nuclear dump in Spain since this would only become a monument which anti-nuclear and anti-American forces could utilize for the political purposes. DOD officials argued that a reading of 50,000 cpm was perfectly safe and requested the Embassy to secure Spanish approval for using this level as the benchmark for soil removal. The Department of Defense proposed to remove all soil with readings above this level and to plow under and water down soil with lesser readings.[29]

(~~S~~)Based on advice provided by the U.S Atomic Energy Commission, the Department of State believed that a reading level of 100,000 cpm was perfectly satisfactory to protect public health and instructed the Embassy to seek an accord on soil removal based on that level as the benchmark. In order to assist Embassy and Department of Defense representatives in Spain, the Atomic Energy Commission sent two American nuclear energy specialists to Madrid in early February. Dr. John Hall was the Assistant Director for International Relations for the AEC. Dr. Wright Langham was the AEC's expert on plutonium contamination. He had previously worked at the Palomares site. Langham would remain in Madrid until mid-March to serve both as the Embassy contact with the JEN and as a special advisor to Ambassador Duke on nuclear matters. In addition to providing advice for Ambassador Duke, both men were instructed to provide technical explanations to buttress the U.S. positions in negotiations with the Spanish Goverment over soil clean-up operations. The State Department also provided the Embassy with a Washington interagency-approved position paper on detcontamination for use in dealing with the Spanish Government. This paper reiterated U.S. concern that the Spanish cpm level guideline for soil removal was much too low and would needlessly delay decontamenation operations to the detriment of both Spanish tourism and public relations aspects of the Palomares recovery while feeding local fears regarding the effects of radiation.[30]

(~~S~~)Armed with this technical aid, the Embassy arranged a meeting between U.S. and Spanish atomic energy experts on February 15. American scientists argued that the 100,000 cpm benchmark for soil removal was adequate for public health and safety. The Spanish scientists did not contest this position on technical grounds but would not accept it as the basis for continuing decontamination operations. U.S. officials were aware that clearance of their proposal would require action at a higher and political level of the Spanish Government. On February 17, the U.S. scientists and the chief of JUSMG met with representatives of the High General Staff. The Spaniards continued to press for soil removal to the 7000 cpm level. The

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U.S. representatives repeated their arguments for utilization of a 100,000 cpm benchmark. Finally, the two sides reached a compromise. The United States would plow up two plots of ground registering a 60,000 cpm reading. In one plot the plowing would reach a depth of 8 inches. This land would be watered and broken up in the internationally-accepted manner proscribed for decontamination. The second plot would be plowed to the depth of 4 inches--the depth normally plowed by Spanish farmers. If readings taken on these two plots were at a normal level, the Spanish Government would abandon its demands for soil removal to the 7,000 cpm level. A copy of the Washington interagency paper and a copy of the telegram outlining the verbal agreement are attached as appendices C and D respectively.[31]

~~(S)~~The Department of State approved the compromise but expressed reservations about utilizing a 60,000 cpm benchmark for soil removal, arguing that this might set a precedent for future decontamination operations which would needlessly complicate U.S. efforts. It provided suggested wording for an agreement with the Spanish Government which would permit the United States to hold to a 100,000 cpm level as the benchmark for future clean-up operations.[32]

~~(S)~~The soil testing was completed on February 21, 1966. U.S. and Spanish scientists agreed that the cpm levels registered after the experiment were at "reasonable levels" for public heath and safety. Based on these conclusions, the Spanish Government abandoned its 7,000 cpm benchmark. Contaminated soil already collected was shipped to the United States for final disposal. The remaining areas were plowed under and watered down. The benchmark of 60,000 cpm became the practical measure for soil removal.[33]

THULE, GREENLAND, JANUARY 1968

(U)At approximately 3:40 pm, January 21, 1968, a SAC B-52 bomber carrying nuclear weapons crashed on the 7-foot-thick ice of North Star Bay approximately 7 miles from the runway at Thule AFB. The aircraft had been attempting an emergency landing after a fire broke out in its heating system. Six crewmen bailed out successfully and were subsequently rescued. A seventh died during the bailout procedure. The four nuclear devices remained within the aircraft and broke up upon impact. Alpha radiation was released in the crash site area. In addition, small fragments from the aircraft passed through the ice pack and settled at the bottom of North Star Bay.

(U)The B-52 crash occurred at a particularly sensitive time for the government of Danish Prime Minister Jens Otto Krag, since a national election campaign was in its final days. The Danish Government, upon receipt of information of the crash (apparently through military channels), released a statement (January 22, 1968) which claimed that Denmark did not permit flights by nuclear armed aircraft over any part of its national territory, including Greenland, and stressed that the plane had been attempting an emergency landing after encountering inflight problems. The text of this statement was not cleared with the U.S. Government prior to its release. The United States had operated its nuclear armed aircraft over Greenland since the conclusion of a 1957 agreement with the Government of Denmark.[34]

(U)Because the wreckage was located in a remote and lightly populated area, claims did not play a major role in the Thule incident. The distance between the crash site and Denmark reinforced the clear division of responsibility between the military and U.S. Embassy already evident after the Palomares accident. The Department of Defense took charge of the recovery and clean-up operations at the crash site, and assumed responsibility for the payment of claims arising from the accident. In addition, the Defense Department public relations teams took charge of the press covering the recovery operation in Greenland and were the primary source of information for reporters in Washington. However, Denmark's democratic politics put an even greater premium on the skillful handling of public relations by Ambassador Katherine White and the Embassy staff in Copenhagen.

Initial Public Relations Efforts

(~~S~~)Within hours of the first news of the crash, the Embassy faced a mounting volume of requests from Danish journalists to travel to Thule. These requests were referred through the Air Attache to the USAF Foreign Liaison Office. The Embassy cautioned both the Departments of State and of Defense that U.S. failure to grant permission to travel to Thule AFB and to facilitate the work of the press in this frigid area would create serious political problems since it would be interpreted as an affront to Danish territorial sovereignty.[35]

(~~S~~)The lessons of Palomares concerning the need for a good public relations program were in the forefront of U.S. Government concern in Washington. On January 23, the Assistant Secretary of State for European Affairs, John Leddy, met with Danish Ambassador Torben Ronne. Leddy opened the discussion by stressing the need for providing the press with as much information as possible, consonant with security requirements, on both the crash and the clean-up operation. He pointedly cited the bad precedents created by press censorship at Palomares. Leddy secured Ambassador Ronne's approval for a Department of Defense press release describing the findings of a ground survey team at the crash site. Ronne urged the quickest possible release of the document. The United States repeatedly cleared its press releases with the Danish Government during the first stages of the Thule operation. This action may have been designed to establish reciprocity with the Danes on public relations issues. If so, the effort failed. The Danish Government repeatedly issued statements without prior U.S. approval.[36]

(U)The immediate problem for both governments was insuring the availability of proper support and transportation for Danish and American reporters desiring to visit Greenland. In addition to troublesome climatic conditions, the arrival of reporters threatened to overwhelm the limited facilities of Thule AFB already straining under the requirements of supporting recovery operations in sub-zero temperatures. In spite of protests by local commanders, the U.S. Government insisted that facilities be provided for the press. Fortunately, the forbidding conditions in Greenland and other major stories (in particular the capture of the U.S.S. Pueblo and the Tet offensive) quickly diverted international press attention. By early February the press corps had left Thule but the story remained a major item of interest in Denmark.[37]

Reaction in Denmark

(U)The need to provide accurate and credible information on the Thule accident was underlined by the response of the Danish press. Anti-American feeling, fueled by the war in Vietnam, reached its peak in Europe during the late 1960's. Even normally pro-American parts of that press publicly called into question the honesty of the U.S. Government and reported that U.S. aircraft had frequently overflown Greenland, fueling suspicion that the United States had violated its agreements with the Danish Government. Danish participation in the study of the nuclear effects of the crash, however, strengthened the credibility of U.S. public statements.[38]

(U)Due to the distances and time problems involved in coordinating information between Washington, Thule, and Copenhagen, Embassy press officers played a limited role in the U.S. public relations effort which was the primary responsibility of Air Force public relations teams at Thule AFB and in Washington. The Embassy information officer, in cooperation with the Air Attache and Embassy press office, arranged transportation for 21 Danish and European journalists to Thule and accompanied them on the visit. The press office also managed to coordinate a nearly simultaneous release of information with Washington by taking down the texts of Department of Defense press bulletins over the phone, copying them, and then providing them to Danish journalists. Department of Defense films on nuclear safety were flown from Washington to Copenhagen for screening by the Danish press. The European Command of the U.S. Army provided the Embassy with a specialist in nuclear matters who assisted press office personnel in preparing and delivering press briefings on such potentially sensitive subjects as safe levels of radioactivity and decontamination procedures. The Embassy also reported that it found a Department of Defense guidance on nuclear matters, prepared after the Palomares accident, of value in its dealings with the press.[39]

(U)On February 5, 1968, the U.S. command at Thule began sending a daily report to Washington and the Embassy on the clean-up operations, designed for briefing the press. The daily information summary was replaced on March 16, 1968 by a system of infrequent releases marking new stages in the progress of the clean-up operation. In the meantime, Danish press interest in the Thule crash began to recede. U.S. cooperation with the Government of Denmark on health and environmental safety overcame the effects of initially hostile press reporting and reestablished credibility with the Danish

public. As early as February 8 Danish scientists returning from Thule reported that no evidence existed of immediate danger to the population of Greenland from the crash.[40] To further strengthen the sense of U.S. concern, Ambassador White made a personal visit to the Thule area on February 24-28. White initially proposed a personal visit to the site on February 2. The Ambassador was accompanied by her Deputy Chief of Mission and by a delegation of Danish Government officials and press. Both White and Danish officials stressed the speed and efficiency of the clean-up operations at a press conference.[41] The program of combining the quick release of accurate information, facilitating the travel and accommodations of Danish and foreign journalists, and cooperation with the Government of Denmark paid major dividends for the United States by improving the tone of Danish press coverage and increasing public confidence in the ability and determination of the United States to handle the clean-up operations safely.

Clean-Up Operations

(~~S~~)The inhabitants of the Thule area, an estimated 650 Greenlanders, were never in any danger of direct contamination from the crash. The area around the crash site was immediately sealed off By Thule AFB personnel to prevent any chance of contamination of the population. Local concern about the effects of radiation centered on indirect contamination through the entry of plutonium into the food chain. Of particular concern was the possibility that radioactive wreckage might have passed through the ice flow and contaminated the sea floor. Statements issued by scientists from the Danish Atomic Energy Commission who participated in the clean-up operations and by thesubsequent follow-up examination of the ocean floor conducted during the summer of 1968 by the Department of Defense greatly allayed these fears.[42]

(U)During the winter, Department of Defense directed clean-up operations centered on recovery of aircraft wreckage, including pieces of the four nuclear weapons, and the collection of contaminated ice and snow. The major problems facing the military were delays caused by bad weather and the assembling of adequate equipment. Core samples were taken from the ice to ascertain the depth to which radioactivity had penetrated. The clean-up proceeded from the edges of the crash site to the center so the burned-out crash impact area was the last to be cleaned up. Recovered debris together with contaminated water were then packed and shipped to the United States for final disposal.

~~(S)~~The clean-up operations produced only minimal economic disruption for the inhabitants of Thule. Most of the restricted area was reopened for use in April and the SAC clean-up operation was finished by mid-April. Tests run by Danish scientists on the plant and marine life in the area during the spring indicated that the crash had had no effect on the local ecology. In August 1968, U.S. submarine vehicles scanned the ocean floor for missing debris, [redacted] A few small pieces of debris which did not pose a threat of contamination were discovered.[43] Most of the discussions relating to nuclear clean-up and monitoring of the crash site were carried out by scientific teams representing the two governments. The U.S. team was organized and led by the Department of Defense. The Embassy played no significant role in clean-up operations.

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Nuclear Overflight and Storage

(U)In matters relating to nuclear policy the Embassy in Denmark played a much more restricted role than did the Embassy in Spain after the Palomares accident. The Danish Government chose to utilize its Embassy in Washington to convey its views and carry on most of the substantive negotiations on nuclear policy questions with the United States.

~~(S)~~The major objective of the Government of Denmark in its discussions with the United States was to secure a joint statement that no atomic weapons were stored in Greenland and that the frequently-observed B-52 flights into Thule and over Greenland were by aircraft that did not carry nuclear armament. (The Danish press was full of stories quoting Greenlanders who claimed that B-52 aircraft regularly flew over the island and landed at Thule AFB.) The United States, as a matter of policy, wished to avoid any statements regarding the storage or transporation of its nuclear armaments. On January 26, 1968, U.S. Assistant Secretary of State Leddy submitted to the Danes a draft statement which avoided any mention of the nuclear issue. Leddy noted that [redacted] the United States and Denmark had agreed in 1957 that their 1951 defense accord granted the United States the right both to store weapons at Thule AFB and to overfly Greenland with nuclear armed aircraft. Leddy also underlined U.S. irritation over the Danish Govenment's failure to consult with it prior to making public statements on nuclear policy.[44]

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~~(S)~~On February 7, shortly after the formation of a new Danish Government, Ambassador White met with Foreign Minister Poul Hartling at the Dane's request. Hartling presented White

with the text of a statement which he planned to read to the Danish parliamentary committee on foreign affairs. This statement assured parliament that no nuclear weapons were stored in Greenland and that the new ministry was entering into negotiations with the United States to insure that none would in the future. White replied that U.S. policy was neither to confirm nor deny matters relating to nuclear arms. Hartling assured the Ambassador that this statement did not imply that his government intended to seek to renegotiate the 1951 defense cooperation agreement. These assurances were repeated to White by Ambassador Ronne, who had returned to Copenhagen for consultations following the formation of a new ministry. Ronne stressed the need for U.S. comprehension of Denmark's position. The Danish Government apparently hoped to win Embassy endorsement for its action in making a public statement on nuclear storage and overflights.[45] ~~B1, B3~~

(U) The following day the Danish parliament passed a motion instructing its government to seek "absolute guarantees" from the United States that Denmark would remain a nuclear-free zone.

(~~S~~) During the negotiations which followed, the Embassy played a secondary role: providing information on public opinion, the attitudes of Danish civilian and military officials, and the negotiating positions of the Danish Government and suggesting U.S. negotiation strategy based on this information. Talks between the United States and Denmark took place in Washington.[46]

(~~S~~) The United States sought to preserve its rights to nuclear storage and overflights as outlined in the 1957 agreement. Negotiations conducted by Assistant Secretary of State Leddy and Ambassador Ronne resulted in a May 31, 1968 exchange of notes between the two governments which supplemented the 1951 defense agreement. The United States agreed that it would neither store atomic weapons in Greenland nor initiate overflights of Danish territory without prior consultations with the Government of Denmark. However, in a separate oral statement to Ronne (May 10), Leddy noted that conditions of extreme and sudden peril to the Atlantic Alliance which did not permit sufficient time for consultations with the Danish Government might lead the United States unilaterally to resume overflights of Greenland. The Danish Government dropped its request for a U.S. statement endorsing its position on nuclear weapons (May 16) and subsequently issued a unilateral declaration which reaffirmed its earlier statements. In keeping with its standing policy, the United States made no comment.[47] ~~B1, B3~~

Coordination Between the Embassy and the Recovery Operation

(U)Distance and the isolation of the crash site warrented the Embassy policy of non-interference in recovery operations. In addition, the Embassy had no contingency plans for coping with a nuclear accident and the Embassy officers had no training in this field. Moreover, the Mission in Denmark lacked specialists in nuclear affairs and in the days following the crash urgently sought the loan of a qualified specialist in nuclear affairs from the Embassy in Stockholm. As earlier noted, the Department of Defense came to the rescue when it authorized the loan of an officer from the European Command with the necessary technical expertise and the ability to deal with the press.

(~~C~~)Nevertheless, the Embassy played an important though limited role in facilitating contact between U.S. and Danish scientists. Ambassador White insisted on acting as the go-between for Defense Department scientists and their Danish counterparts. The Embassy did the groundwork for a joint meeting at Copenhagen between a team of U.S. scientists led by Dr. Carl Walske, Assistant Secretary of Defense for Nuclear Energy, and representatives of the Danish Atomic Energy Agency. All messages between the U.S. scientific team and the Danish Government were sent through the Embassy in order to maintain . . . excellent coordination among all American agencies which has characterized . . . B-52 crash."[48] The Embassy also provided communications facilities between the Department of Defense Science Team and Washington. Initially, communications between the DOD and Danish representatives travelled through a number of channels. However, once the Embassy became aware of this, it insisted that all future contacts must go through it, permitting the State Department to stay up to date with the scientific and technical aspects of the negotiations over the clean-up operation.[49]

(~~S~~)The Embassy also played an important role in the coordination of the texts of joint U.S.-Danish statements on scientific and technical aspects of the clean-up and recovery operations. Finally, during the summertime U.S. and Danish ecological surveys of North Star Bay and environs, Embassy officials worked with the representatives of the Danish Government on the public information program.[50]

(U)Overall cooperation between the Embassy and Department of Defense representatives was extremely close and appears to have been unmarred by any serious policy or personality disputes.

Claims

(U)The Danish Government declined to press any claims against the United States arising from the accident. The Department of Defense handled the payment of local claims arising from the accident. These claims were minimal and the Embassy does not appear to have taken any role in the settlement procedures.[51]

CONCLUSIONS

(U)While the documentation available for this study was not sufficient to trace the daily activities of either the Ambassador or the Embassy staffs during the crises which followed the crash of B-52's at Palomares and Thule, it does permit certain conclusions concerning the role of the Ambassador, the tasks performed by the Embassy, and the relationship of the Embassy to the U.S. military during the recovery and clean-up operations.

(U)Both Ambassadors confined themselves to traditional diplomatic functions, seeking to establish cooperation with the host government and to provide information which would put U.S. actions in the most favorable light before the publics of Spain, Denmark, and Greenland. Still, a good deal of flexibility existed for the definition of the ambassadorial role during these incidents and the degree to which the Ambassador took a hand in the resolution of events was determined by the circumstances of the accident and the personality of the incumbent. On the whole, Ambassador Duke took a more active role than Ambassador White both in diplomatic exchanges with the host government and in the public diplomacy function of his mission.

(U)Geography was a factor in the role which Ambassadors had in these crises. Although Palomares was situated in a remote part of Spain, it was on the European mainland and close enough to the centers of Spain's booming tourism trade to endanger part of Spain's economy as well as heighten concern about the possibility of an accidental nuclear explosion throughout the western Mediterranean area and northern Europe. The B-52 crash near Thule occured in a virtually uninhabited area, offshore, and close to a U.S. military facility. These factors in the Thule incident led to greater Department of Defense control and less Embassy involvement.

(U)The differing experiences and managerial styles of the two Ambassadors also interacted with the particular circumstances of the two incidents. Both Ambassadors were political appointees, but Duke had previously served as Chief of Protocol at the Department of State and, possessing a more complete knowledge of the foreign policy-making apparatus in Washington, was potentially in a better position to gain acceptance of his views. More importantly, Duke's particular situation required a more aggressive representation of U.S. interests. The United States was seeking to preserve its nuclear rights and to widen the scope of the information made

issues related to the clean up and to claims arising from the accident. This made the Embassy in Spain and the Ambassador a key figure in the complex negotiations which finally resolved the Palomares incident.

(~~S~~)On the other hand, within hours of the crash at Thule, the Danish Government began aggressively seeking concessions from the United States through their Ambassador in Washington. Thus the Embassy in Denmark was largely bypassed on matters of policy and handled more routine matters. Moreover, the documentation indicates that Ambassador White handed responsibility for these matters to her deputy chief of mission who, while very active, probably lacked the weight with both the highest levels of the Danish Government and senior U.S. officials which an Ambassador often enjoys.

(U)The Embassy role in both episodes was almost exclusively non-technical in character. Inadequately staffed to handle the scientific and technical problems arising from the accidents, both Embassies relied upon the Department of Defense, the Atomic Energy Commission, and the Department of State for technical advice. This essential technical support was quickly available in Spain but was not immediately available in the Danish case. Coordination on technical matters, such as clean-up, decontamination, and weapons recovery, was performed primarily by the Defense attaches who utilized their familiarity with the agencies and commands of the Defense Department and with the military establishment of the host nation to provide the Embassy with accurate information and advice. In addition, in Spain, the Chief of JUSMG was able to utilize a close relationship with Munoz Grandes to improve inter-governmental cooperation on the recovery and clean-up operations and to assist the Embassy's ultimately unsuccessful efforts to regain Spanish permission for overflights by nuclear armed aircraft

(U)Throughout both incidents the overriding concerns of the Embassy were the impact of the accident on the U.S. public image and the retention of special rights and privileges relating to the movement and storage of nuclear weapons. The Embassy in Spain faced almost unsurmountable public relations problems due to the authoritarian nature of the Spanish regime which sought to impose a heavy-handed censorship on the press and thus increased public concerns and suspicions. Profiting from the lessons of the Palomares incident and from the requirements of Danish democracy, the Embassy in Denmark was able to create a more successful public relations effort after the Thule accident.

(~~S~~) Neither Embassy was able to influence significantly the host government on the matter of U.S. nuclear weapons rights. In the case of Denmark, the decision was made to revoke those rights within hours of the Thule crash. In the case of Spain, the Embassy's efforts were undercut by the inability of U.S. recovery teams to find the missing nuclear device and a resultant public outcry which drove the Franco regime toward a cancellation of permission for U.S overflights.

(U) Cooperation between the agencies of the Defense Department and the Embassies was good. In Spain, the Embassy felt compelled to prod the military over the speed of its claims repayment operation, but also provided the Department of Defense with badly-needed assistance in negotiations over both claims settlements procedures and standards for contamination clean-up.[52]

(U) Finally, both missions inherited responsibility for final settlement of legal problems arising from the crash. In the case of the Embassy in Denmark, these responsibilities were very limited due to the site of the crash and the disinclination of the Danish Government to press any claims. The Palomares crash, however, produced a long lasting series of headaches for the Embassy in Spain, arising primarily from legal claims but also involving the actions of opponents of the Franco regime. The Embassy in Spain continues to take action on problems related to the 1966 crash at Palomares.

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NOTE ON SOURCES

(U)This study was based on the files of the Department of State. In preparing it, primary reliance was placed on the Madrid and Copenhagen Post files and upon the files of the Danish Desk. The Central files of the Department of State were also consulted but they yielded little useful information. Other sources included press accounts, books published in the aftermath of the Palomares accident and information supplied by officers of the Department of State.

NOTES

1. Madrid tel. 839, Jan. 17, 1966, Confid-Nofor. Def 18 Madrid Post Files (Hereinafter cited MPF). On the release of information to the press, cf. Madrid tel. 846, Jan. 17, 1966, Confid., Def 17, MPF. Detailed accounts of the initial actions of the embassy staff are in Tad Szulc, The Bombs of Palomares (NY, 1967), pp. 54-62 and Flora Lewis, One of Our H-Bombs Is Missing (NY, 1967), pp. 63-68. Both are based on interviews conducted shortly after the acident.

2. Tel. 839 from Madrid, Jan. 17, 1966, Confid. op. cit.

3. Deptel. 851 to Madrid, Jan. 22, 1966, Secret, Def 18.1, MPF. Unnumbered Department of Defense tel. to the Embassy in Madrid, Jan. 22, 1966, ibid. Cf. Madrid tel. 838, Jan. 21, 1966, Def. 17, ibid.

4. Madrid tels. 855 and 857, Jan. 19, 1966, both Secret. Madrid 859, Jan. 20, 1966, Secret, all Def 17, MPF. DOD officials at Palomares initially attempted to place a veil of secrecy around all aspects of the accident to avoid exposure of the nuclear weapons on board the B-52. Szulc, whose presentation of the activities of the Embassy is consistently favorable, is highly critical of U.S. military efforts at press control and later DOD public affairs programs. He enjoyed a good relationship with Embassy personnel and his criticisms of the military public relations effort, in addition to reflecting a reporter's pique with the efforts at a news blackout, apparently magnified Embassy frustrations with the DoD handling of its on-site press briefings. Bombs of Palomares, pp. 114-15, 123, 168-69, 214-15. Lewis, while critical of the DOD public relations effort more accurately places most of the blame for the lack of information on the Spanish Government and notes U.S. Embassy irritation with Spain's efforts at censorship. One of Our H-Bombs, pp. 101-02, 176.

5. Madrid tel. 871, Jan. 22, 1966, Secret, Def 17, MPF.

6. Ibid.

7. Madrid tel. 869, Jan. 21, 1966, Confid. Cf. Madrid tel. 873, Jan. 23, 1966, Confid. Tel. JUSMG to CINCEUR, Jan. 22, 1966, Secret, all Def 17, MPF. See, Szulc, The Bombs of Palomares, p. 117 on trend of press reporting.

8. Madrid tel. 896, Jan. 26, 1966, Secret. Madrid tel. 914, Jan. 29, 1966, Confid., all Def 17, MPF. The extra-legal opposition capitalized on the crash to mount a small and peaceful demonstration outside the U.S. Embassy on Feb. 2, 1966. Franco's police eventually broke this march up.

9. Madrid tel. 951, Feb. 5, 1966, Secret, Def 17, MPF. Notes of a conversation with Ambassador Duke, Feb. 2, 1966, Secret, Def 18.1 MPF. Madrid tel. 966, Feb. 9, 1966, Confid, Def 17,MPF. The proposal for a Palomares press conference was turned down in Deptel. 941, Feb. 12, 1966, Secret, Def 18.1, MPF. No rationale for this decision was outlined in the telegram When Duke's proposal failed to win the agreement of the Spanish Government, the Embassy suggested a joint TV appearance by U.S. and Spanish scientists. Madrid tel. 974, Feb. 11, 1966, Confid., Def 17, MPF. Cf. Szulc, Bombs of Palomares, pp. 168-69.

10. Madrid tel. 942, Feb. 4, 1966, Confid., Def 17, MPF. A somewhat garbled version of this incident is in Szulc, Bombs of Palomares, p. 175.

11. Madrid tel. 1020, Feb. 18, 1966, Secret. Madrid tel. 1066, Feb. 25, 1966, Confid., both Def 17, MPF.

12. Madrid tel. 1099, Mar. 2, 1966, Secret, Def 17, MPF.

13. Ortiz to Duke, Jan. 20, 1966, Confid., Def. 18.1, MPF. Szulc, Bombs of Palomares, pp. 219-227 for further details.

14. Madrid tel. 1239, Mar. 22, 1966, Confid., Def 17, MPF.

15. On the problems of the recovery operation and its efect on press relations, see Sculz, Bombs of Palomares, pp. 234-45; Lewis, One of Our H-Bombs, p. 213.

16. Madrid tel. 1276, Mar. 26, 1966, Secret, Def 17, MPF.

17. Unnumbered telegram from Madrid to the Secretary of Defense, Mar 24, 1966, Confid. Madrid tel. 1269, Mar. 25, 1966, Secret, both Def 17, MPF. Sculz, Bombs of Palomares, pp. 215-16, reprints part of one of the press conferences which vividly present the press relations problems created by efforts to avoid admitting that a nuclear weapon was missing:
Reporter: "Tell me, any sign of the bomb?"
USAF Spokesman: "What bomb?"
Reporter: "Well, you know, the thing you're looking for..."
USAF Spokesman: "You know perfectly well we're not looking for any bomb. Just for debris."

Reporter: "All right, any signs of the thing which you say is not the bomb?"
USAF Spokesman: "If you put it that way, I can tell you that there is no sign of the thing that is not the bomb."
Sculz adds: "And so it went for days, for weeks." The New York Times (March 4, 1966.) greeted the March admission that a bomb was in fact missing with the caustic comment that it took the United States only 40 days to acknowledge the truth. On Embassy officials complaints to the press about being treated as nuisances, Szulc, Bombs of Palomares, p. 171. On growing Embassy disstaisfaction with the public relations operation and stains between Embassy officials and DOD representatives; cf., Notes, "Action," Jan. 24, 1966, Unclass., Def 18.1, MPF. "Ambassador's Comments on Return from Almeria," Feb. 3, 1966, ibid.

18. Cf, Szulc, Bombs of Palomares, pp. 226-27.

19. Madrid tel. 1359, April 7, 1966, Confid., Def 17, MPF.

20. Munoz Grandes request was reported in Madrid tel. 1264, March 25, 1966, Confid., Def 17, MPF.

21. Cf. Deptel. 118041, Jan. 14, 1967, LOU, Def 17-Palomares, MPF. On the problem with the duchess, Madrid tel. 1800, Jan. 13, 1967, LOU, Def 17, MPF. On the problems with the desalination plant, cf. Madrid 1557, Jan. 12, 1966, Confid., Def 17, MPF. See also the post morta in Time, Jan. 24, 1969, pp. 41-42., Washington Post, Feb. 9, 1969, and Atlas, Dec. 1971, pp. 78-79.

22. Madrid tel. 1316, April 1, 1966, Secret, Def 12, MPF.

23. Madrid tel. 1444, April 22, 1966, Secret, Def 17, MPF.

24. Madrid tel. 1531, May 6, 1966, Secret, Def 17-1, MPF. Madrid tel. 1836, June 23, 1966, Secret, Def 12, MPF. Madrid tel. 1555, December 16, 1966, Secret, Def 17-1, MPF.

25. Madrid tel. 997, Feb. 12, 1966, Secret, Def 17, MPF.

26. Madrid tel. 1025, Feb. 19, 1966, Secret. Madrid tel. 1031, Feb. 21, 1966, Secret. Madrid tel. 1038, Feb. 21, 1966, LOU, all Def 17, MPF. On the claims settlement procedures, see Defense Nuclear Agency, "Palomares Summary Report," Jan. 15, 1975 (U), pp. 149-81. A copy of the agreement on claims procedures is attached as appendix A to this paper.

27. Memorandum of a conversation between Duke and Aguirre de Carcer, Director General of North American Affairs, Spanish

Foreign Office, Madrid, Jan. 5, 1967, Confid, Def 17, MPF. Notes of discussion with Harvey Ferguson, INR/WEA, Nov. 1, 1984. Ferguson was Economics Officer in Madrid in 1976.

28. Madrid tel. 888, Jan. 25, 1966, Confid-Limdis. Madrid tel. 887, Jan. 25, 1966, Confid. Memorandum from Wilson to Duke, Jan 26, 1966, Secret, all Def 17, MPF.

29. Defense Nuclear Agency, "Palomares Summary Report," pp. 44-73 for details. A copy of the Wilson-Montel agreement is included as appendix B to this paper. For objections to the notion of a nuclear waste site in Spain, see tel. from Chief of JUSMG to the Chief of Staff of the Air Force, Feb. 3, 1966, Secret, Def 18.1, MPF.

30. State tel. 941 to Madrid, Feb. 12, 1966, Secret. State tel. 942 to Madrid, Feb. 12, 1966, Secret, both Def 18.1, MPF. A copy of the interagency paper is included as appendix C to this paper.

31. Madrid tel. 995, Feb. 15, 1966, Secret. Madrid tel. 1019, Feb. 18, 1966, Secret, both Def 17, MPF. A copy of the telegram outlining this verbal agreement is attached as appendix D to this paper.

32. State tel. 993 to Madrid, Feb. 19, 1966, Secret, Def 17, MPF.

33. Madrid tel. 1031, Feb. 21, 1966, Secret. Madrid tel. 1054, Feb. 25, 1966, Confid., Def. 17, MPF.

34. The text of this statement and the text of a telegram reporting Danish agreement are attached as appendix E to this paper.

35. Copenhagen tel. 2837, Jan. 22, 1968, Secret, Def 17, Copenhagen Post Files. Hereinafter cited CPF.

36. Memorandum of a conversation between Leddy and Ronne, Washington, Jan. 23, 1968, Secret.

37. Copenhagen tel. 2863, Jan. 23, 1968, Unclass., Def 17, CPF.

38. Copenhagen tel. 2949, Jan. 28, 1968, Unclass., Def 17 B-52, CPF.

39. Copenhagen tel. 1340, Feb. 2, 1968, LOU. PAO Monthly report for January 1968, Feb. 21, 1968, Unclass., both Def 17 B-52, CPF. The "information guidance" referred to was no. 5329 sent to Madrid on March 3, 1966. No copy of this guidance was found in the Madrid Post files.

40. Copenhagen tel. 1552, Mar. 3, 1968, Unclass., Def 17 B-52, CPF.

41. Copenhagen tel. 1341, Feb. 2, 1968, LOU. Tel. from 4683 AB Group Thule to the Department of Defense, Feb. 29, 1968, Unclass., Def 17, B-52, CPF.

42. Tel. from the SAC Disaster Control Team, Thule, to the Embassy in Denmark, Jan. 28, 1968, Confid. Tel. from Thule AFB to the Department of Defense, Jan. 28, 1968, Unclass. Tel. from the Department of Defense to the Embassy in Denmark, Jan. 30, 1968, Secret. Copenhagen tel. 1358, Feb. 8, 1968, Def 17 Greenland Crash, CPF.

43. Memorandum from Leddy (EUR) to Rusk (S), Feb. 23, 1968, Confid., Lot 73D170, "Thule Crash-Internal Memos." Memorandum on the Thule Operation, April 10, 1968, Unclass., Lot 73D170, Thule Crash--Information, General." Memorandum from George Springsteen (EUR) to Rusk (S), July 22, 1968, Secret, "Lot 73D170, "Thule Crash-Clean-Up Operation." State tel. 231303 to Copenhagen, Aug. 31, 1968, LOU, Def 17 B-52, CPF.

44. Memorandum of a conversation between Leddy and Ronne, Jan. 26, 1968, Secret, Def 17 B-52, CPF.

45. Copenhagen tel. 1352, Feb. 7, 1968, Confid. Copenhagen tel. 1360, Feb. 8, 1968, Confid., both Def 17 B-52, CPF.

46. Copenhagen tel. 1389, Feb. 14, 1968, Confid., Def 17 B-52, CPF. Copenhagen tel. 1395, Feb. 15, 1968, Secret, Def 15, CPF. Copenhagen tel. 1401, Feb 16, 1968, Secret. Letter from Byron Blankinship (DCM, Copenhagen) to David McKillop (Director, EUR/SCAN), Copenhagen, Feb. 23, 1968, Confid., both Def 17 B-52, CPF.

47. President's Evening Reading, May 9 and 31, 1968. Letter from Leddy to Paul Warnke, Assistant Secretary of Defense, April 17, 1968, Secret, both Lot 73D170, "Thule Crash-Internal Memos." The memoranda outlining this agreement are attached as appendix F to this paper.

48. Copenhagen tel. 3210, Feb. 10, 1968, Unclass. Letter from White to Goulding, Assistant Secretary of Defense, Feb. 12, 1968, Unclass., Def 17, CPF.

49. Copenhagen tel. 3346, Feb. 16, 1968, Confid., Def 17 B-52, CPF.

50. Copenhagen tel. 1431, Feb. 27, 1968, LOU. Copenhagen tel. 5684, July 18, 1968, Secret, both Def 17 B-52, CPF.

51. Copenhagen tel. 4315, April 22, 1968, Unclass., Def 17 B-52, CPF. Letter from White to Goulding, op cit.

52. In spite of disagreements over public relations matters and other irritants, the level of cooperation between Embassy and on-site DOD teams was so satisfactory that Ambassador Duke wrote a three page letter to Secretary of the Air Force Harold Brown, praising the performance of General Wilson, the commander of the clean-up operation. Duke to Brown, May 10, 1966, Def. 18.1, MPF.

AFRRI
SPECIAL REPORT

DoD nuclear mishaps

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AFRRI SP86-2

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APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

The following information concerning U.S. nuclear weapon accidents has been collected from materials released by the Department of Defense (DoD) in 1977, 1980, and 1981, and also from several media references. This publication is intended to be a source document in the course "Medical Effects of Nuclear Weapons," which is sponsored by the Armed Forces Radiobiology Research Institute.

The United States has never had an inadvertent nuclear detonation, even a partial one, despite the very severe stresses imposed on the weapons that might be involved in accidents. All "detonations" reported in the DoD summaries involved only conventional high explosives. Only two accidents, those at Palomares and Thule, resulted in widespread dispersal of nuclear materials.

Nuclear weapons are never carried on training flights. Most of the aircraft accidents described here occurred during logistic/ferry missions or airborne alert flights by Strategic Air Command (SAC) aircraft. Airborne alert was terminated in 1968 because of

- Accidents, particularly those at Palomares and Thule;
- The rising cost of maintaining a portion of the SAC bomber force constantly on airborne alert;
- The advent of a responsive and survivable intercontinental ballistic missile force, which relieved the manned bomber force of a part of its more time-sensitive responsibilities. (A portion of the SAC force remains on nuclear ground alert.)

Since the location of a nuclear weapon is classified defense information, it is DoD policy, normally, to neither confirm nor deny the presence of a nuclear weapon at any specific location. In the case of an accident involving a nuclear weapon, the weapon's presence may or may not be divulged at the time, depending on the possibility of public hazard or alarm. Therefore, for some of the events summarized in this publication, the presence of a nuclear weapon or material may not have been confirmed at the time. Furthermore, due to diplomatic considerations, it is not possible to specify the locations of the accidents that occurred overseas, except for Palomares and Thule.

Most of the weapon systems involved in these accidents are no longer in the active inventory. Those include the B-29, B-36, B-47, B-50, B-58, C-124, F-100, and P-5M aircrafts and the Minuteman I Missile.

With some early models of nuclear weapons, it was a standard safety procedure during most operations to keep a capsule of nuclear material separate from the weapon. Although a weapon with the capsule removed did contain a quantity of natural (not enriched) uranium with an extremely low level of radioactivity, the accidental detonation of the high-explosive element would not cause a nuclear detonation or contamination. Modern designs incorporate improved safety features, to ensure that a nuclear explosion does not occur as the result of an accident.

MANAGEMENT OF THE NUCLEAR WEAPON STOCKPILE

The management of nuclear weapons is shared by the Department of Energy (DOE) and DoD. The Secretary of Energy and the Secretary of Defense are directly responsible to the President, who retains the sole authority for weapons employment. DOE, as successor of the Atomic Energy Commission, is responsible for all research, development, test, and production of nuclear weapons. DOE is the only Government agency that is authorized by statute to engage in these activities. By law, DOE is required also to control and account for all active nuclear material, including the U.S. stockpile of war-reserve nuclear weapons. These weapons have been entrusted to DoD for employment readiness in case the President orders their use in the interest of national security. Ownership, however, is retained by DOE.

To carry out these responsibilities, the DOE organization includes a network of Government-owned laboratories, plants, and test sites in nine states, all operated by private industry or institutions under Government contract. There are three design and development laboratories, manufacturing facilities, and a field test capability.

At the policy level, DOE's Division of Military Applications (DMA) interfaces with DoD's Military Liaison Committee (MLC). DMA is DOE's primary liaison with DoD, and it provides major program guidance and direction for weapons research and development directly to the weapons laboratories. The Defense Nuclear Agency (DNA) provides some elements of the DoD liaison function with DOE. DNA is a joint service agency under the Joint Chiefs of Staff, with headquarters in Washington, DC, and its operating unit, Field Command, Defense Nuclear Agency, located in Albuquerque, New Mexico.

The MLC Chairman is the Assistant to the Secretary of Defense for Atomic Energy, and is responsible for management and control policies for all nuclear weapon functions within DoD. MLC consists of two senior officers from each Service, with the DNA Director and DOE's DMA Director acting as observers. The DoD nuclear weapon program and requirements are provided to DOE through MLC.

WEAPON SAFETY CONCEPTS

Since DOE designs, develops, and produces all nuclear weapons, it is primarily responsible for the safety features and devices within the weapons. DoD is responsible for safe and secure operations external to the weapon. Considerable overlap and interaction exist, with DoD participating in weapon design (for familiarity and to coordinate requirements) and DOE assisting in the development of safety rules for operating the total nuclear weapon system.

To understand the philosophy of nuclear weapon safety, it is important to first understand the basic nuclear physics involved. Unlike conventional explosives that derive their sensitive properties from their basic chemical makeup, a nuclear device must be specifically designed to bring about an explosion. To obtain a nuclear reaction or explosion through fission, an amount of active material sufficient to produce a continuous, self-sustaining nuclear reaction must be assembled so that a "supercritical mass" can be attained. One technique used to achieve a supercritical mass is called "implosion." In contrast to the outward burst of an explosion, implosion is an inward compression. In a nuclear weapon, high

explosive surrounds the nuclear material. A simultaneous firing of detonators mounted on the surface of the high explosive produces a shock wave that compresses the nuclear material. The important feature is the simultaneous firing of the detonators and control of the shock wave to achieve symmetrical compression of the nuclear material, and thus attain a supercritical mass.

The implosion process used to detonate a nuclear weapon, by its very nature, has a built-in safety feature. If the high explosive detonates at any single point for any reason, including fire or shock as a result of an accident, there would be no symmetrical implosion. The shock wave moving from a single point on the high-explosive surface would explode and destroy the device. This would release and perhaps scatter the active material, but would not result in a nuclear explosion.

In our latest weapons, a new, insensitive high explosive is used, which is extremely stable and will not explode on impact or in a fire. This will dramatically reduce the possibility of nuclear materials being scattered in an accident.

The current DOE safety-design concept packages the weapon-detonation subsystem into an "exclusion region." This feature follows a design philosophy intended to prevent undesired electrical energy from reaching the nuclear weapon detonator system. Included in this concept is a series of "weak links" and "strong links" to obtain predictably safe responses in abnormal environments such as fire, deep water, lightning, cruising impacts, or impact from high-velocity projectiles. The strong links are open switches that close only when the proper signals are received. The weak links are elements vital to the operation of the detonator system. These links are packaged together so that both strong and weak links experience the same environment. Safety is achieved in abnormal environments because the vital components (weak links) are designed to fail first, destroying the detonator system, before the open switches (strong links) can possibly fail to a closed position.

Associated with the exclusion region concept is the design of the strong links to respond only to unique signals. These open switches will not respond to the weapon system's electrical power sources, which might become connected through short circuits during an accident. The unique signals required can be generated by the weapon system only when intended by the human operator.

Nuclear weapons also contain environment-sensing devices that prevent firing of the detonators unless the required environment is experienced. The devices include such items as

- Pullout cables that maintain an open circuit until the cable is physically pulled from the weapon upon release from the aircraft;

- Accelerometers that maintain open circuits until they sense the acceleration or deceleration for a required period of time, as would be produced by a rocket motor or a retarding parachute;

- Barometric switch devices that remain open until they sense the pressure differential that is anticipated in desired release conditions;

- Timers that maintain open switches for a specific time interval after weapon release;

- Electromechanical switches that remain open until a positive action is taken by a human operator.

These safety features and others are designed into the weapon with stringent quality and reliability controls by DoD.

The DoD Safety Program is based on four nuclear safety standards. The standards require that, in the design, development, and employment of a nuclear weapon system, there be positive measures to

- Prevent jettisoned weapons or weapons involved in accidents or incidents from producing a nuclear yield;
- Prevent deliberate prearming, arming, launching, firing, or releasing of nuclear weapons except upon execution of emergency war orders or when directed by competent authority;
- Prevent inadvertent prearming, arming, launching, firing, or releasing of nuclear weapons;
- Ensure adequate security of nuclear weapons.

To satisfy these DoD nuclear safety standards, the Safety Program addresses safety-design engineering for each nuclear weapon system, its logistic and operational environment, and the human factors involved in the maintenance and operation of the weapon system. The various considerations of the program are listed below to give a perspective of their relationships and a feeling for the extent of the Safety Program. The program considerations include

- Requirements and design guidance for safety considerations in nuclear weapon system development;
- Safety engineering evaluation and formal certification before the system can be used with a nuclear weapon;
- Nuclear safety analysis and certification of all computer programs developed for use in the control of the nuclear weapon system;
- Engineering, operational, and logistic studies and reviews of the complete weapon system and its intended environment from storage to target, resulting in weapon system safety rules that prescribe authorized procedures and impose limitations for operation of the nuclear weapon system;
- Approved technical data and maintenance procedures that must be precisely followed in the operation or maintenance of the nuclear weapon system;
- Engineering evaluation and safety certification of all equipment used in the maintenance, movement, and operation of the nuclear weapon system;

- Reporting and analysis of accidents, incidents, and deficiencies that involve the nuclear weapon system, support equipment, and procedures;

- Safing and sealing of critical nuclear weapon system switches;

- Evaluation of all personnel associated with the nuclear weapon system to ensure their emotional stability and proper security clearance before being authorized access to a nuclear weapon, nuclear weapon system, or nuclear command and control facility;

- A "two-man" or "no lone zone" concept around the nuclear weapon and the nuclear weapon system;

- An inspection system to monitor compliance not only with the four DoD safety standards but also with all nuclear safety rules and technical data in all operations involving a nuclear weapon or nuclear weapon system.

In addition to the safety devices contained within the nuclear weapon, the weapon carrier contains devices that prevent prearming or release unless intended. Examples of these devices are

- Dual switches that force two-man consent for both prearm and launch (or release);

- Intent switches that prevent a prearm signal until manually closed by the human operators;

- A unique signal generator, activated by the prearm intent switch, that produces the unique signal required by the weapon's strong links described earlier;

- Intent switches that prevent a nuclear weapon release signal until manually closed by the human operators (separate from the prearm switches);

- Arm-inhibit switches that require a "good guidance" signal from the missile guidance system before warhead arming can occur;

- In-flight reversible mechanical locks on the weapon carriage rack that physically prevent weapon release until electrically activated by the human operators;

- A monitor system to provide the operator the arm/safe status of the nuclear weapon and lock/unlock status of the carriage rack.

Devices such as these prevented weapon arming in the Goldsboro and Palomares accidents. In early bomb racks such as those involved in the accidents at Kirtland Air Force Base, New Mexico, and at Florence, South Carolina, one means to prevent inadvertent release was the insertion of safety pins in the carriage rack. These pins were removed during takeoff and landing to permit emergency jettison. When the safety pins were removed, however, a single failure in the rack could cause an inadvertent release of the nuclear weapon, as shown by these accidents.

A cockpit-controlled, in-flight, reversible lock is now required which, when locked, prevents inadvertent weapon release even though the normal release force is applied. This design allows safe takeoff and landing with the rack in the locked position. The device is designed to fail to the locked position, and also requires an independent positioning of intent switches by two crew members in multiplace aircraft before the rack holding the weapon can be unlocked.

RADIOACTIVE MATERIALS IN NUCLEAR WEAPON ACCIDENTS

Nuclear weapons contain three principal types of radioactive materials: plutonium, uranium, and tritium. Other types of radioactive materials may also be present in lesser and varying amounts, depending on the type and age of the weapon. For accidental contamination, the initial public health risks and protective/corrective actions are the same as those for contamination by particles of plutonium, uranium, and tritium (see below).

The risks to the public from radioactive contamination caused by a nuclear weapon accident are not like fallout from a nuclear bomb blast, and are not like contamination from a major nuclear power plant accident. However, contamination from a nuclear weapon accident could be serious and could require both immediate and long-term protective and corrective cleanup measures. The potential harm to the public and the environment can be controlled best by an effective response to the accident and by providing the public with timely information and instructions about protection from contamination.

Public instructions and appropriate actions will depend on the severity of the accident, the type of material involved, and the length of time between occurrence of the accident and initiation of protective action.

ACCIDENT SEVERITY FACTORS

If nuclear weapons are involved in an accident and the condition of the weapon is not known, the potential for contamination must be assumed. Besides the immediate response around the accident site, protective measures (possible evacuation) for the general public may be necessary within 1 day.

Instructions on basic protective measures should allow time to respond to the accident, to determine the condition of the weapon, and to disseminate supplementary information and instructions to the public.

If damage to a nuclear weapon is known but the weapon is still structurally intact, any potential contamination would be limited to the immediate area of the accident site, and would probably be of very short duration (a few minutes). Keeping the public clear of the accident site and providing information to relieve unwarranted fears (prevent panic) should be sufficient for public protection.

If a nuclear weapon accident results in severe structural damage (scattering of small chunks of the warhead), fire (melting and burning of the warhead), or detonation of the conventional (chemical) high explosive, then more widespread contamination is probable and larger scale protective actions will be necessary. In this case, information and instructions provided to the public will depend on the type of radioactive material and the time since the accident.

PLUTONIUM

Contamination by plutonium particles dispersed by conventional (chemical) explosion or burning of a weapon would pose the most serious health hazard to the public, and could impact the environment over a wide area.

Plutonium is both a poison and a radiation hazard. The radiation given off consists of "alpha particles" (like very fast moving helium atoms), which do not have sufficient energy to penetrate buildings, most clothing, or even the outer skin. Therefore, short-term exposure (up to a few days) to contamination outside of the body will pose only a small health risk.

Plutonium radiation is considered a serious health risk if small "dust-like" pieces are inhaled or ingested and remain as deposits in the body. Even a very small quantity (equivalent to a single piece of dust) inside the body could cause concern as a health risk over the long term. No immediate "radiation sickness" symptoms are expected from this type of contamination.

Unless it is possible to immediately (within minutes) evacuate the area around the accident site and several miles downwind, the best initial public response will probably be to stop outside activity, seek shelter in well-sealed buildings (with little or no use of outside air for heating or cooling), and delay evacuation until the dust cloud has passed and particles have had time to settle out of the air. Besides being medically sound, this procedure will reduce casualties that result from panic and will least affect the critical and essential services.

Any evacuation of the public that does take place must be in a controlled manner, thereby reducing the risk of resuspension of the contaminant and the risk of collateral injury to the civilian population. Any person evacuating an area should breathe through a filter (such as a common dust mask or even several layers of a wet handkerchief), and move with care to avoid stirring up the dust. If resources and time permit, evacuation should include the use of protective outer clothing that can be cleaned for reuse or discarded.

The best direction and timing for travel can be specified for population centers or zones in the area. Factors such as population density, transportation, and facilities in the contaminated area must be considered in deciding whether and when to move the public out of an area.

Whether evacuation is immediate or delayed, panic of the population may result in some injury, death, or property damage. Every effort should be made to state the problem in a way that will inform the public, keep the problem in context, and avoid confusion.

The determination of cleanup requirements and techniques will involve extensive surveys and coordination with experts in several government agencies (Federal Emergency Management Agency, Environmental Protection Agency, DOE, DoD, etc.). Cleanup efforts may extend over several months, and monitoring requirements over several years.

URANIUM

Contamination by uranium fragments or small particles dispersed by a conventional (chemical) explosion or by the burning of a weapon is primarily a chemical health hazard (heavy metal poison similar to the lead poisoning associated with some paints), not a radiological hazard. The short-term risk to health occurs only if a relatively large quantity of uranium is deposited inside the body by inhaling or ingesting the dust. A short-term public hazard from radiation (alpha particles) from uranium is very unlikely. Determination of any long-term radiation (or chemical) hazard will require detailed and extensive surveys.

It is unlikely that uranium contamination, even though dispersed over a wide area, would add significantly to the overall exposure that man normally receives from radioactive materials found in most environments.

TRITIUM

The radiation given off by tritium is a low-energy "beta particle," which is stopped by the outer layers of skin. Thus external exposure is not a hazard. Contamination by tritium gas would pose a health hazard only in a closed or confined space. Tritium released by a weapons accident will dissipate and be diluted so rapidly in open air that no internal hazard would result. Monitoring (air sampling) of the immediate site of the accident is sufficient to assure prevention of exposure to accident-response personnel. Tritium from a weapons accident will not affect the public or the environment.

CLEANUP AFTER A NUCLEAR WEAPON ACCIDENT

An accident that causes a nuclear weapon to structurally break apart, burn, or chemically detonate will contaminate an area of indeterminate size with potentially hazardous materials. These materials may include plutonium, uranium, or high explosive.

The cleanup of explosive and chemical hazards will be relatively straightforward, but the decontamination of any radioactive materials will depend on technically sophisticated surveys and risk assessments.

DETERMINATION OF CONTAMINATION LEVEL

An initial estimate of the size and shape of the contaminated area and of the level of contamination within the area can be provided within a few hours by computer models. This information can be used to determine the actions necessary to protect the public and the scope of the cleanup problem. Then the determination of actual cleanup requirements and preferred techniques will depend on the material involved, field survey measurements of actual contamination levels, and careful assessment of any associated potential health risk.

Cleanup requirements may be minimized if contamination levels are low, or if the contaminating material is trapped and therefore not a hazard to plants, animals, or man. If contamination levels are high and/or the material is a health risk to man, then cleanup requirements may be quite stringent over an extensive area. The cleanup of scattered plutonium would probably present the greatest difficulty.

THE CLEANUP PROCESS

If initial estimates of the contamination level and subsequent field survey measurements indicate radiological contamination in the soil above a screening level of 0.2 microcuries/square meter (or above 1 fCi/m^3), then a careful assessment of health risks is necessary and cleanup may be necessary. Below this screening level, cleanup actions may not be necessary.

SUMMARY OF ACCIDENTS INVOLVING U.S. NUCLEAR WEAPONS, 1950-1980

An "accident involving a nuclear weapon" may be defined as an unexpected event involving a nuclear weapon or nuclear weapon components that results in any of the following:

- Accidental or unauthorized launching, firing, or use by U.S. forces or supported allied forces of a nuclear-capable weapon system that could create the risk of an outbreak of war;
- Nuclear detonation;
- Nonnuclear detonation or burning of a nuclear weapon or radioactive weapon component, including a fully assembled nuclear weapon, an unassembled nuclear weapon, or a radioactive nuclear weapon component;
- Seizure, theft, or loss, including jettison, of a nuclear weapon or radioactive nuclear weapon component;
- Public hazard, actual or implied.

Accidents involving U.S. nuclear weapons from 1950 to 1980 are summarized in the following paragraphs.

1. 13 February 1950 / B-36 / Pacific Ocean, Off Coast of British Columbia

A B-36 aircraft was en route from Eielson AFB to Carswell AFB on a simulated combat profile mission. The weapon aboard the aircraft had a dummy capsule installed. After 6 hours of flight, the aircraft developed serious mechanical difficulties, making it necessary to shut down three engines. The aircraft was at 12,000 feet altitude. Icing conditions complicated the emergency, and level flight could not be maintained. The aircraft headed out over the Pacific Ocean and dropped the weapon from 8,000 feet into the ocean. A bright flash occurred on impact, followed by a sound wave and a shock wave. Only the weapon's high-explosive material detonated. The aircraft was then flown over Princess Royal Island, where the crew bailed out. The aircraft wreckage was later found on Vancouver Island.

2. 11 April 1950 / B-29 / Manzano Base, New Mexico

A B-29 aircraft departed Kirtland AFB at 9:38 p.m. and approximately 3 minutes later crashed into a mountain on Manzano Base, killing the crew. Detonators were installed in the bomb on board the aircraft. The bomb case was

demolished, and some high-explosive material burned in the gasoline fire. Other pieces of unburned high explosive were scattered throughout the wreckage. Four spare detonators in their carrying case were recovered undamaged. Contamination did not occur, and there were no recovery problems. The recovered components of the weapon were returned to the Atomic Energy Commission. The capsule of nuclear material was on board the aircraft but had not been inserted into the weapon for safety reasons. A nuclear detonation was not possible.

3. 13 July 1950 / B-50 / Lebanon, Ohio

A B-50 aircraft was on a training mission from Biggs AFB, Texas, flying at 7,000 feet on a clear day. The aircraft nosed down and flew into the ground, killing 4 officers and 12 airmen. The high-explosive portion of the weapon aboard detonated on impact. There was no nuclear capsule aboard the aircraft.

4. 5 August 1950 / B-29 / Fairfield-Suisun AFB, California

A B-29 carrying a weapon, but no capsule, experienced two runaway propellers and landing-gear-retraction difficulties on takeoff from Fairfield-Suisun AFB (now Travis AFB). The aircraft attempted an emergency landing, crashed, and burned. Fire was fought for 12-15 minutes before the weapon's high-explosive material detonated. Nineteen crew members and rescue personnel, including General Travis, were killed in the crash or the resulting detonation.

5. 10 November 1950 / B-50 / Over Water, Outside the United States

Because of an inflight aircraft emergency, a weapon containing no capsule of nuclear material was jettisoned over water from an altitude of 10,500 feet. A high-explosive detonation was observed.

6. 10 March 1956 / B-47 / Mediterranean Sea

The aircraft was one of a flight of four scheduled for nonstop deployment from MacDill AFB to an overseas air base. The takeoff from MacDill and the first refueling were normal. The second refueling point was over the Mediterranean Sea. In preparation, the flight penetrated solid cloud formation to descend to the refueling level of 14,000 feet. The base of the clouds was 14,500 feet, and visibility was poor. The aircraft never made contact with the tanker. An extensive search failed to locate any trace of the missing aircraft or crew. No weapons were aboard the aircraft, only two capsules of nuclear weapon material in carrying cases. A nuclear detonation was not possible.

7. 27 July 1956 / B-47 / Overseas Base

A B-47 aircraft with no weapons aboard was on a routine training mission and making a touch-and-go landing, when the aircraft suddenly went out of control. It slid off the runway and crashed into a storage igloo containing several nuclear weapons. The bombs did not burn or detonate; they were in storage configuration. No capsules of nuclear materials were in the weapons or present elsewhere in the building. There were no contamination or cleanup problems. The damaged weapons and components were returned to the Atomic Energy Commission.

8. 22 May 1957 / B-36 / Kirtland AFB, New Mexico

The B-36 aircraft was ferrying a weapon from Biggs AFB, Texas, to Kirtland AFB. At 11:50 a.m., MST, as the aircraft approached Kirtland at an altitude of 1,700 feet, the weapon dropped from the bomb bay, taking the bomb bay doors with it. Weapon parachutes were deployed but apparently did not fully retard the fall because of the low altitude. The impact point was approximately 4.5 miles south of the Kirtland control tower and .3 mile west of the Sandia Base reservation. The high-explosive material detonated, completely destroying the weapon, and making a crater approximately 25 feet in diameter and 12 feet deep. Fragments and debris were scattered as far as 1 mile from the impact point. The release-mechanism locking pin was being removed at the time of release. (It was standard procedure, at that time, to remove the locking pin during takeoff and landing, to allow emergency jettison of the weapon if necessary.) The recovery and cleanup operations were conducted by Field Command, Armed Forces Special Weapons Project. Radiological survey of the area disclosed no radioactivity beyond the lip of the crater, at which point the level was 0.5 milliroentgens. There were no health or safety problems. A nuclear capsule was on board the aircraft but had not been inserted into the weapon for safety reasons. A nuclear detonation was not possible.

9. 28 July 1957 / C-124 / Atlantic Ocean

Two weapons were jettisoned from a C-124 aircraft off the east coast of the United States. The C-124 aircraft was en route from Dover AFB, Delaware, when a loss of power from the number one and number two engines was experienced. Maximum power was applied to the remaining engines, but level flight could not be maintained. At this point, the decision was made to jettison cargo in the interest of safety of the crew and aircraft. Three weapons and one nuclear capsule were aboard the aircraft, and nuclear components had not been installed in the weapons. The first weapon was jettisoned at 4,500 feet altitude. The second weapon was jettisoned at approximately 2,500 feet altitude. No detonation occurred from either weapon. Both weapons are presumed to have been damaged from impact with the ocean surface, and to have submerged almost instantly. The ocean varies in depth in the area of the jettisons. The C-124 landed at an airfield in the vicinity of Atlantic City, New Jersey, with the remaining weapon and the nuclear capsule aboard. A search for the weapons or debris had negative results.

10. 11 October 1957 / B-47 / Homestead AFB, Florida

The B-47 departed Homestead AFB shortly after midnight on a deployment mission. Shortly after lift-off, one of the aircraft's outrigger tires exploded. The aircraft crashed in an uninhabited area approximately 3,800 feet from the end of the runway. The aircraft was carrying one weapon in ferry configuration in the bomb bay and one nuclear capsule in a carrying case in the crew compartment. The weapon was enveloped in flames, and it burned and smoldered for approximately 4 hours, at which time it was cooled with water. Two low-order high-explosive detonations occurred during the burning. The nuclear capsule and its carrying case were recovered intact and only slightly damaged by heat. Approximately one half of the weapon remained. All major components were damaged but were identifiable and accounted for.

11. 31 January 1958 / B-47 / Overseas Base

A B-47 with one weapon in strike configuration was making a simulated takeoff during an exercise alert. When the aircraft reached approximately 30 knots on the runway, the left rear wheel casting failed. The tail struck the runway, and a fuel tank ruptured. The aircraft caught fire and burned for 7 hours. Firemen fought the fire for the allotted 10-minute fire-fighting time for the high-explosive contents of that weapon, and then evacuated the area. The high explosive did not detonate, but some contamination did occur in the immediate area of the crash. No contamination was detected after removal of the wreckage and the asphalt beneath it and after washing down of the runway. One fire truck and one fireman's clothing showed slight alpha contamination before washing. Following the accident, exercise alerts were temporarily suspended and B-47 wheels were checked for defects.

12. 5 February 1958 / B-47 / Savannah River, Georgia

The B-47 was on a simulated combat mission that originated at Homestead AFB, Florida. While near Savannah, Georgia, the B-47 had a mid-air collision with an F-86 aircraft at 3:30 a.m. Following the collision, the B-47, with a weapon aboard, attempted to land three times at Hunter AFB, Georgia. Because of the condition of the aircraft, its airspeed could not be reduced enough to ensure a safe landing. Therefore, the decision was made to jettison the weapon rather than expose Hunter AFB to the possibility of a high-explosive detonation. A nuclear detonation was not possible since the nuclear capsule was not aboard the aircraft. The weapon was jettisoned into the water several miles from the mouth of the Savannah River (Georgia) in Wassaw Sound off Tybee Beach. The precise impact point of the weapon is unknown. The weapon was dropped from an altitude of approximately 7,200 feet at an aircraft speed of 180-190 knots. No detonation occurred. After jettison, the B-47 landed safely. A 3-square-mile area was searched by divers and underwater demolition team technicians using galvanic drag and hand-held sonar devices. The weapon was not found. The search was terminated on 16 April 1958. The weapon was considered to be irretrievably lost.

13. 11 March 1958 / B-47 / Florence, South Carolina

At 3:53 p.m., EST, a B-47E departed Hunter AFB, Georgia, as number three aircraft in a flight of four en route to an overseas base. After level off at 15,000 feet, the aircraft accidentally jettisoned an unarmed nuclear weapon that impacted in a sparsely populated area 6.5 miles east of Florence, South Carolina. The bomb's high-explosive material exploded on impact. The detonation caused property damage and several injuries on the ground. The aircraft returned to the base without further incident. No capsule of nuclear materials was aboard the B-47 or installed in the weapon.

14. 4 November 1958 / B-47 / Dyess AFB, Texas

A B-47 caught fire on takeoff. Three crew members successfully ejected; one was killed when the aircraft crashed from an altitude of 1,500 feet. One nuclear weapon was on board when the aircraft crashed. The resultant detonation of the high explosive made a crater 35 feet in diameter and 6 feet deep. Nuclear materials were recovered near the crash site.

15. 26 November 1958 / B-47 / Chennault AFB, Louisiana

A B-47 caught fire on the ground. The single nuclear weapon on board was destroyed by the fire. Contamination was limited to the immediate vicinity of the weapon residue within the aircraft wreckage.

16. 18 January 1959 / F-100 / Pacific Base

The aircraft was parked on a revetted hardstand in ground alter configuration. The external load consisted of a weapon on the left intermediate station and three fuel tanks (both inboard stations and the right intermediate station). When the starter button was depressed during a practice alter, an explosion and fire occurred when the external fuel tanks inadvertently jettisoned. Fire trucks at the scene put out the fire in about 7 minutes. The capsule was not in the vicinity of the aircraft and was not involved in the accident. There were no contamination or cleanup problems.

17. 6 July 1959 / C-124 / Barksdale AFB, Louisiana

A C-124 on a nuclear logistics movement mission crashed on takeoff. The aircraft was destroyed by fire, which also destroyed one weapon. No nuclear or high-explosive detonation occurred; safety devices had functioned as designed. Limited contamination was present over a very small area immediately below the destroyed weapon. This contamination did not hamper rescue or fire-fighting operations.

18. 25 September 1959 / P-5M / Pacific Ocean Off the Washington Coast

A U.S. Navy P-5M aircraft assigned to Naval Air Station, Whidbey Island, Washington, crashed in the Pacific Ocean about 100 miles west of the Washington-Oregon border. It was carrying an unarmed nuclear antisubmarine weapon containing no nuclear material. The weapon was not recovered.

19. 15 October 1959 / B-52 / KC-135 / Hardinsburg, Kentucky

The B-52 departed Columbus AFB, Mississippi, at 2:00 p.m., CST. The aircraft assumed the number two position in a flight of two. The KC-135 departed Columbus AFB at 5:33 p.m., CST, as the number two tanker aircraft in a flight of two scheduled to refuel the B-52's. Rendezvous for refueling was accomplished in the vicinity of Hardinsburg, Kentucky, at 32,000 feet. It was night; the weather was clear, with no turbulence. Shortly after the B-52 began refueling from the KC-135, the two aircraft collided. The instructor pilot and pilot of the B-52 ejected, followed by the electronic warfare officer and the radar navigator. The copilot, navigator, instructor navigator, and tail gunner failed to leave the B-52. All four crew members in the KC-135 were fatally injured. The B-52's two unarmed nuclear weapons were recovered intact. One had been partially burned, but did not result in dispersion of nuclear material or other contamination.

20. 7 June 1960 / BOMARC / McGuire AFB, New Jersey

A BOMARC air defense missile in ready storage condition (permitting launch in 2 minutes) was destroyed by explosion and fire after a high-pressure helium tank exploded and ruptured the missile's fuel tanks. The warhead was also destroyed by

the fire, although the high explosive did not detonate. Nuclear safety devices functioned as designed. Contamination was restricted to an area immediately beneath the weapon and an adjacent elongated area approximately 100 feet long, caused by drain-off of fire-fighting water.

21. 24 January 1961 / B-52 / Goldsboro, North Carolina

During a B-52 airborne alert mission, structural failure of the right wing resulted in two weapons separating from the aircraft during aircraft breakup at 2,000-10,000 feet. One bomb parachute deployed, and the weapon received little impact damage. The other bomb fell free and broke apart upon impact. No explosion occurred. Five of the eight crew members survived. A portion of one weapon, containing uranium, could not be recovered despite excavation in the waterlogged farmland to a depth of 50 feet. The Air Force subsequently purchased an easement requiring permission for anyone to dig there. No detectable radiation and no hazard exist in the area.

22. 14 March 1961 / B-52 / Yuba City, California

A B-52 experienced failure of the crew compartment pressurization system, forcing descent to 10,000 feet altitude. Increased fuel consumption caused fuel exhaustion before rendezvous with a tanker aircraft. The crew bailed out at 10,000 feet except for the aircraft commander, who stayed with the aircraft to 4,000 feet and steered the plane away from a populated area. The two nuclear weapons on board were torn from the aircraft on ground impact. The high explosive did not detonate. Safety devices worked as designed to prevent nuclear contamination.

23. 13 November 1963 / Atomic Energy Commission Storage Igloo / Medina Base, Texas

An explosion involving 123,000 pounds of high-explosive components of nuclear weapons caused minor injuries to three Atomic Energy Commission employees. There was little contamination from the nuclear components, which were stored elsewhere in the building. The components were from the disassembly of obsolete weapons.

24. 13 January 1964 / B-52 / Cumberland, Maryland

A B-52D was en route from Westover AFB, Massachusetts, to its home base at Turner AFB, Georgia. The crash occurred approximately 17 miles southwest of Cumberland, Maryland. The aircraft was carrying two weapons, which were in a tactical ferry configuration (no mechanical or electrical connections had been made to the aircraft, and the safing switches were in the "SAFE" position). Before the crash, the pilot had requested a change of altitude because of severe air turbulence at 29,500 feet. The aircraft was cleared to climb to 33,000 feet. During the climb, the aircraft encountered violent air turbulence, and aircraft structural failure then occurred. Of the five air-crew members, only the pilot and copilot survived. The gunner and navigator ejected, but died of exposure to subzero temperatures after successfully reaching the ground. The radar navigator did not eject and died upon aircraft impact. The crash site was an isolated mountainous and wooded area. The 14 inches of new snow covered the aircraft wreckage, which was scattered over an area of approximately 100 square yards. The weather during the recovery and cleanup operation involved extreme cold and

gusty winds. Both weapons remained in the aircraft until it crashed, and were relatively intact in the approximate center of the wreckage area.

25. 5 December 1964 / LGM 30B (Minuteman ICBM) / Ellsworth AFB, South Dakota

The LGM 30B Minuteman I missile was on strategic alert at Launch Facility L-02, Ellsworth AFB, South Dakota. Two airmen were dispatched to the Launch Facility to repair the inner zone security system. In the midst of their checkout of the inner zone system, one retrorocket in the spacer below the Reentry Vehicle (RV) fired, causing the RV to fall about 75 feet to the floor of the silo. When the RV struck the bottom of the silo, the arming and fusing/altitude control subsystem containing the batteries was torn loose, thus removing all sources of power from the RV. The RV structure received considerable damage. All safety devices operated properly in that they did not sense the proper sequence of events to allow arming the warhead. There was no detonation or radioactive contamination.

26. 8 December 1964 / B-58 / Bunker Hill (now Grissom) AFB, Indiana

SAC aircraft were taxiing during an exercise alert. As one B-58 reached a position directly behind the aircraft on the runway ahead of it, the aircraft ahead brought advanced power. As a result of the combination of the jet blast from the aircraft ahead, the icy runway surface conditions, and the power applied to the aircraft while attempting to turn onto the runway, control was lost and the aircraft slid off the left side of the taxiway. The left main landing gear passed over a flush-mounted taxiway light fixture, and 10 feet farther along in its travel, grazed the left edge of a concrete light base. After another 10 feet, the left main landing gear struck a concrete electrical manhole box, and the aircraft caught on fire. When the aircraft came to rest, all three crew members aboard abandoned the aircraft. The aircraft commander and defensive systems operator egressed with only minor injuries. The navigator ejected in his escape capsule, which impacted 548 feet from the aircraft. He did not survive. Portions of the nuclear weapon on board burned. Contamination was limited to the immediate area of the crash and was subsequently removed.

27. 11 October 1965 / C-124 / Wright-Patterson AFB, Ohio

The C-124 aircraft was being refueled in preparation for a routine logistics mission when a fire occurred at the aft end of the refueling trailer. The fuselage of the aircraft, containing only components of nuclear weapons and a dummy training unit, was destroyed by the fire. There were no casualties. The resultant radiation hazard was minimal. Minor contamination was found on the aircraft, cargo, and clothing of explosive ordnance disposal and fire-fighting personnel, and was removed by normal cleaning.

28. 5 December 1965 / A-4 / Pacific Ocean

An A-4 aircraft loaded with one nuclear weapon rolled off the elevator of a U.S. aircraft carrier and fell into the sea. The pilot, aircraft, and weapon were lost. The incident occurred more than 500 miles from land.

29. 17 January 1966 / B-52 / KC-135 / Palomares, Spain

The B-52 and the KC-135 collided during a routine high-altitude-air refueling operation. Both aircraft crashed near Palomares, Spain. Four of the eleven crew members survived. The B-52 carried four nuclear weapons. One was recovered on the ground, and one was recovered from the sea on 7 April after extensive search and recovery efforts. Two of the weapons' high-explosive materials exploded on impact with the ground, releasing some radioactive materials. Approximately 1400 tons of slightly contaminated soil and vegetation were removed to the United States for storage at an approved site. Representatives of the Spanish Government monitored the cleanup operation.

30. 21 January 1968 / B-52 / Thule, Greenland

A B-52 from Plattsburgh AFB, New York, crashed and burned approximately 7 miles southwest of the runway at Thule AB, Greenland, while approaching the base to land. Six of the seven crew members survived. The bomber carried four nuclear weapons, all of which were destroyed by fire. Some radioactive contamination occurred in the area of the crash, which was on the sea ice. Some 237,000 cubic feet of contaminated ice, snow, water, and crash debris were removed to an approved storage site in the United States over the course of a 4-month operation. Although an unknown amount of contamination was dispersed by the crash, environmental sampling showed normal readings in the area after the cleanup was completed. Representatives of the Danish Government monitored the cleanup operations.

31. Spring 1968 / Atlantic Ocean

Details remain classified.

32. 19 September 1980 / Titan II ICBM / Damascus, Arkansas

During routine maintenance in a Titan II silo, an Air Force repairman dropped a heavy wrench socket, which rolled off a work platform and fell toward the bottom of the silo. The socket bounced and struck the missile, causing a leak from a pressurized fuel tank. The missile complex and the surrounding area were evacuated, and a team of specialists was called in from Little Rock AFB, the missile's main support base. About 8.5 hours after the initial puncture, fuel vapors within the silo ignited and exploded. The explosion fatally injured one member of the team. Twenty-one other USAF personnel were injured. The missile's reentry vehicle, which contained a nuclear warhead, was recovered intact. There was no radioactive contamination.

NOTE: The events outlined here involved operational weapons, nuclear materials, aircraft, and/or missiles under control of the U.S. Air Force, U.S. Navy, or the Atomic Energy Commission (the DOE predecessor agency). The U.S. Army has never experienced an event classified as an accident involving nuclear weapons. The U.S. Marine Corps does not have custody of nuclear weapons in peacetime, and has not experienced an accident involving them.

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A SUMMARY OF ACCIDENTS AND SIGNIFICANT INCIDENTS

INVOLVING U.S. NUCLEAR WEAPONS

AND NUCLEAR WEAPON SYSTEMS (U)

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW

1ST REVIEW-DATE: 6/97
AUTHORITY: ☐ DC ☒ DD
NAME: BILL LAWRENCE
2ND REVIEW-DATE: 1.5.99
AUTHORITY: DD
NAME: Holly Kemper

DETERMINATION (CIRCLE NUMBER(S))
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3. CONTAINS NO DOE CLASSIFIED INFO
4. ~~COORDINATE WITH:~~ AF HHS
5. CLASSIFICATION CANCELED
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TABLE I - SUMMARY OF ACCIDENTS INVOLVING US NUCLEAR WEAPONS

ACCIDENT NUMBER	DATE	LOCATION	WEAPON CONFIGURATION			TYPE OF ACCIDENT	NUCLEAR WEAPON RESPONSE		
			ASSEMBLED WEAPONS	UNASSEMBLED WEAPONS	COMPONENTS ONLY		HE RESPONSE		CONTAMINATION
							HE BURN	HE DETONATE	
1	02/13/50	Puget Sound, WA	-	X	-	Jettison, 8000'			
2	04/11/50	Manzano Base, NM	-	X	-	Crash into mountain			
3	07/13/50	Lebanon, OH	-	X	-	Crash in dive			
4	08/05/50	Fairfield-Suisan AFB, CA	-	X	-	Emergency landing, fire			
5	11/10/50	Over water, outside US	-	X	-	Jettison			
6	03/10/56	At sea (Mediterranean)	-	-	X	Aircraft lost			
7	07/27/56	SAC Base	-	X	-	B-47 crashed into bunker			
8	05/22/57	Kirtland AFB, NM	-	X	-	Inadvertent jettison			
9	07/28/57	At sea (Atlantic)	-	X	-	Jettisons, 4500' & 2500'			
10	10/11/57	Homestead AFB, FL	-	X	-	Crash on takeoff, fire			
11	01/31/58	SAC base overseas	X	-	-	Taxi exercise, fire			
12	02/05/58	Savannah, GA	-	X	-	Mid-air collision, jettison			
13	03/11/58	Florence, SC	-	X	-	Accidental jettison			
14	11/06/58	Dyess AFB, TX	X	-	-	Crash on takeoff			
15	11/26/58	Chenault AFB, LA	X	-	-	Fire on ground			
16	01/08/59	US base, Pacific	-	X	-	Ground alert, fuel tanks on fire			
17	07/06/59	Barksdale AFB, LA	X	-	-	Crash on takeoff, fire			
18	09/25/59	Off Whidbey Is., WA	-	X	-	Navy aircraft ditched			
19	10/15/59	Hardinsburg, KY	X	-	-	Mid-air collision, impact			
20	06/07/60	McGuire AFB, NJ	X	-	-	Missile fire			
21	01/24/61	Goldsboro, NC	X	-	-	Mid-air breakup			
22	03/14/61	Yuba City, CA	X	-	-	Crash after abandonment			
23	11/13/63	Medina Base, TX	-	-	X	Storage igloo at AEC plant			
24	01/11/64	Cumberland, MD	X	-	-	Mid-air breakup, crash			
25	12/05/64	Ellsworth AFB, SD	X	-	-	Missile re-entry vehicle fell			
26	12/08/64	Bunker Hill AFB, IN	X	-	-	Taxi crash, fire			
27	10/11/65	Wright-Patterson AFB, OH	-	-	X	Transport a/c fire on ground			
28	12/05/65	At sea, Pacific	X	-	-	Aircraft rolled off elevator			
29	01/17/66	Palomares, Spain	X	-	-	Mid-air collision, crash			
30	01/21/68	Thule, Greenland	X	-	-	Crash after abandonment			
31	Spng '68	At sea, Atlantic	X	-	-	Lost weapons			
32	09/19/80	Damascus, AK	X	-	-	Missile fuel explosion			

NOTES:

1. USAF 09/19/77 press release to Richard Panter, Eye-Witness News Boston, obtained under the Freedom of Information Act, supplemented by DOD per Appendix I.

2. The term "Assembled Weapon" means either that the separable nuclear capsule was installed but was not in the bomb's pit or a sealed-pit type of weapon with the nuclear material integral with the HE subsystem. "Unassembled Weapons" means that the separable nuclear capsule was not installed in the weapon. (The USAF press release for accidents 1-13 used the term "assembled weapon" for the above plus where a capsule was on the aircraft.

3. Contamination from all accidents except 29 & 30 was low in radioactivity and highly localized in area affected.

4. In the parentheses, the first number indicates the number of weapons that had the named response, and the second number gives the total involved in the accident.

DOE 6(3)

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Accident #29 Palomares, Spain 7/17/66:

1. A B-52 Aircraft carrying four Mk 28 Y1 Mod 2 War Reserve Weapons in an MHU-20/C Clip-in Assembly collided with a KC-135 Tanker at an altitude of approximately 30,500 feet during an overwater refueling operation. Both aircraft were destroyed.

2. The first weapon was found to be relatively intact with the loading lugs still engaged in the MB-3 Release mechanism. The tail closing plate was torn away from the rear case and the pilot chute had deployed. The bomb nose was depressed slightly and three of the fins had been torn away. The Arm-Safe Switch indicated SAFE. In accordance with rendering safe procedures, the weapon battery was removed. DOE b(3)

3. The primary of the second weapon which impacted in the village apparently underwent a low order detonation. DOE b(3)

The afterbody was fairly intact and the pilot chute had deployed. The weapon case and internal weapon components were badly broken and mangled by impact and detonation. DOE b(3)

4. The third weapon which impacted in rocky hills also experienced a low order detonation of the primary explosives. DOE b(3)

The crater measured approximately 20 feet across and six feet deep. The afterbody and parachute pack were blown approximately 100 yards from the crater. The mild detonating fuze had detonated and the pilot chute had spilled out. The main chute was out of the ruptured afterbody case but was retained in the chute cover. DOE b(3)

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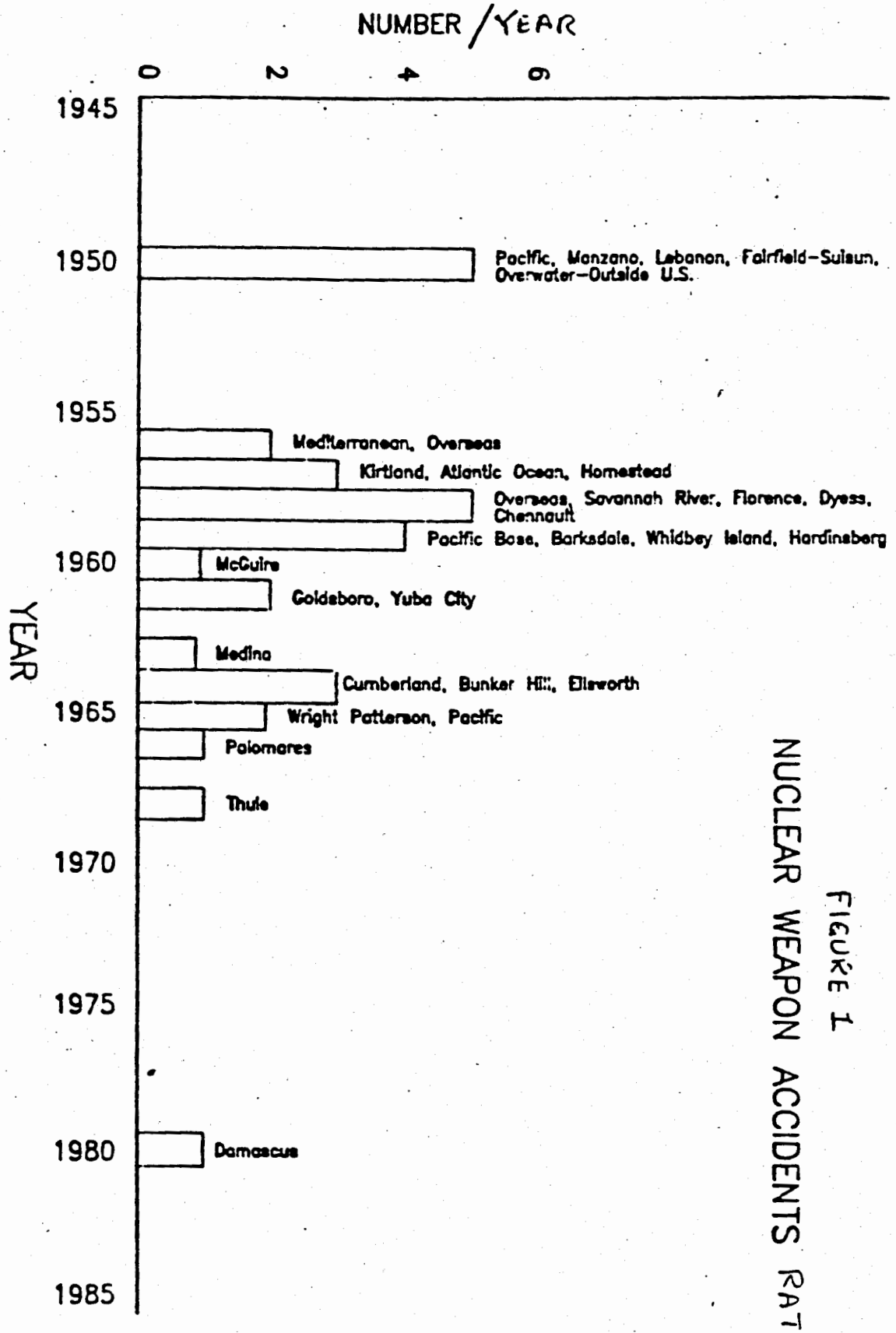


FIGURE 1

NUCLEAR WEAPON ACCIDENTS RATE

summary, of the nuclear weapons involved in the accidents since 1950:

...One of the 16 weapons (accident 4, Table I) involved in accidents with liquid hydrocarbon fuel fires (7 accidents) or missile propellant fuel fires (1 accident) experienced high-order HE detonation.

...Five of the 11 weapons involved in aircraft crashes (6 accidents) experienced HE detonation.

...Five of the ten weapons involved in accidents with free-falls (8 accidents) experienced HE detonation on impact. Free falls resulted from ejected missiles (1 accident), aircraft which broke-up in mid-air (2 accidents), jettisons (5 accidents). Neither of the two weapons involved in aircraft ditching (1 accident) or aircraft rolling off of a ship (1 accident) detonated.

...None of the three bombs involved in accidents (2 accidents) with retarded falls from high altitudes experienced HE detonation on impact.

..[redacted] DOE b(3)

In this total accident experience, there were two instances where extensive decontamination was performed: the Palomares, Spain, and Thule, Greenland accidents which involved dispersal of plutonium by detonation of the weapons' HE on impact. For the two instances where the plutonium melted as a result of the HE burning, only minor local decontamination (mostly washing and removing asphalt) was performed. None of the seven incidents involving uranium dispersal required decontamination.

RESTRICTED DATA
SECRET

Declassified document RR00045 containing data on B53 safing, e.g. spiking capacitor bank to prevent unauthorized use.

Option #	Option Description	Relative Safety Improvement				Relative Increase In Time, Dollars, or People	Nuclear Detonation Safety And Scatter Effectiveness Ranking (1 = Best)		Weapon Security Improvement	New Equipment or Procedures	Ranking And Whether To Do or Not Do (1 = Best)		Comments
		During Transportation		During Storage			Trans.	Storage			Ranking	Do or Don't	
		Nuclear Yield	Pu Scatter	Nuclear Yield	Pu Scatter								
1	Remove D-T Gas Reservoir	None	N/A	None	N/A	Med	-	-	None	None	-	Do	Alt 916
2	Disconnect Input Cables to X-Unit	Med	N/A	Med	N/A	Med	5	3	Low	Low	4	-	Impractical
3	Provide TARC	Med	N/A	N/A	N/A	High	2	N/A	Low	High	5	Don't	No Pu, too big etc.
4	Use SST Only	Med	N/A	N/A	N/A	Low	1	N/A	High	None	1	Do	
5	Remove Thermal Batteries	Med	N/A	Med	N/A	Med	4	2	Low	Low	2		
6	"Spike" the X-Unit Capacitors	Med	N/A	Med	N/A	Med	3	1	Med	Med	3		

Chart 1. Retrograde Surety, B53-1 Safety Options

SECRET
RESTRICTED DATA

DOE
D(3)

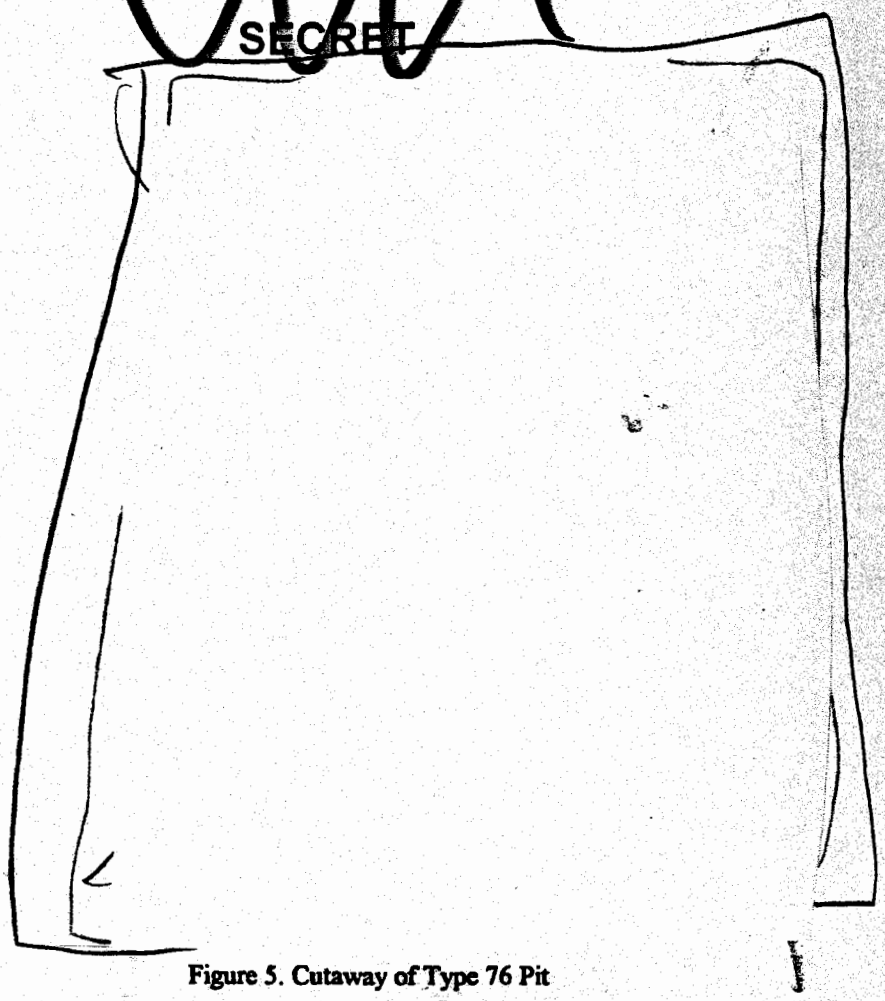
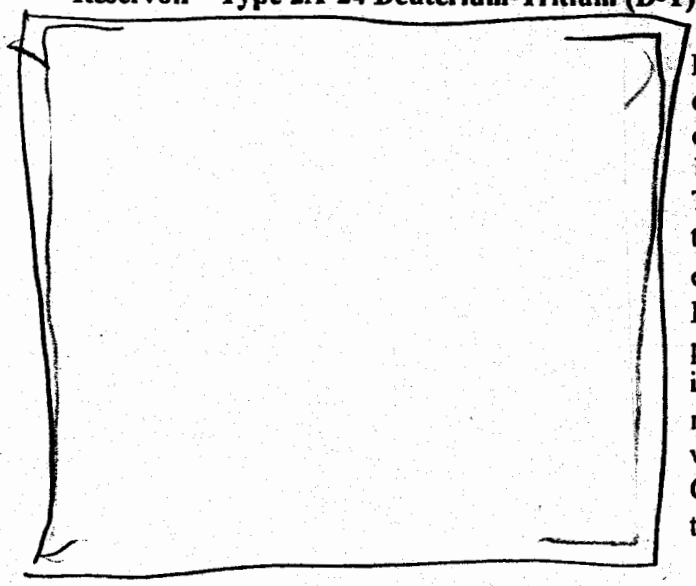


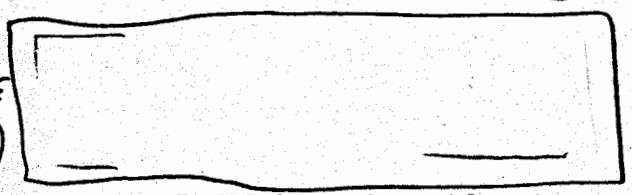
Figure 5. Cutaway of Type 76 Pit

Reservoir - Type 2A-24 Deuterium-Tritium (D-T) gas reservoir and valve assembly

DOE
D(3)



Each Type 1A squib contains an electro-exploding device (EED) that initiates 25 mg of lead styphnate, which in turn initiates 175 mg of Ball Powder (black powder). The Type 1A valve assembly contains a visible thermal plug that is designed to open in a fire environment (operating temperature 104°C). If the actuator squibs fire with the thermal plug open, the gas generated by the actuators is vented to the outside and the plunger will not be forced onto the reservoir and pit tubes with enough velocity to cut the tubes. Cutting these tubes is the only way of transferring the D-T gas to the pit.

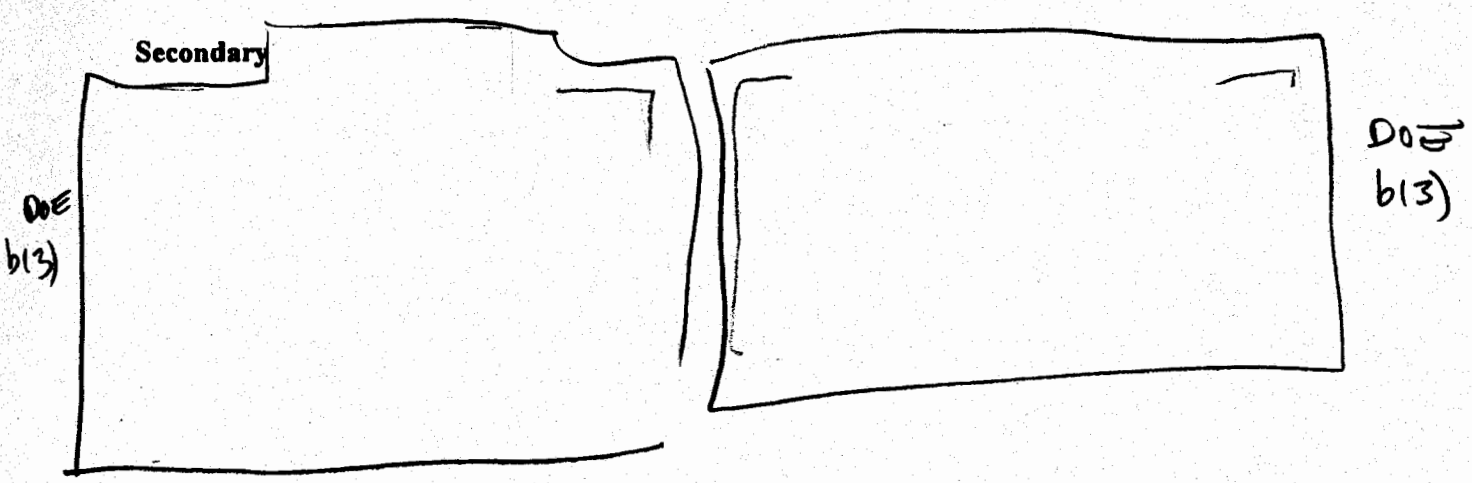


Cycle Life - The interval from the fill time to the time that the gas no longer meets the weapon yield certification because of Tritium decay. This life is used to determine the normal LLCE requirements.

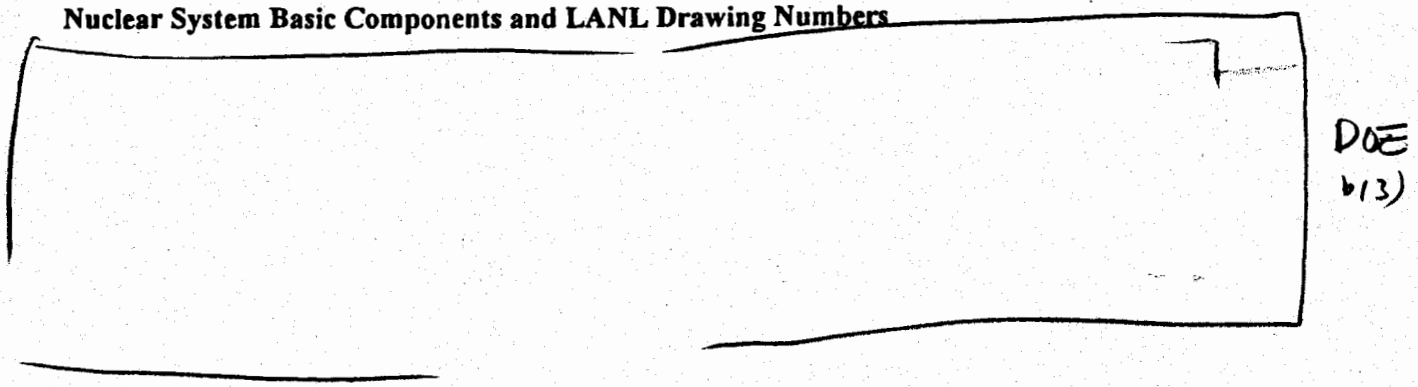
Extended Cycle Life - The interval from the fill time to the time that "unacceptable" yield degradation results from Tritium decay and helium generation. This time is greater than the cycle life and less than or equal to the limit life.

Limit Life - The interval from the fill time to the time that the structural integrity of the reservoir, including an appropriate factor of safety, may be compromised, resulting in an increased probability of a Tritium leak.

Stockpile Life - The total number of years that a reservoir can be exposed to a Tritium environment. It may limit the number of times a reservoir can be refilled.



Nuclear System Basic Components and LANL Drawing Numbers



2. Unique signal is provided by the AMAC to enable the MC2929 strong-link switch (requires approximately 25 seconds).

C. Weapon release:

1. Pullout rods are extracted from the MC1200A Fuzing System Control Selector:

   a. Pullout switches in the main thermal battery output lines closed.
   b. Pulse generators in the MC1200A are actuated initiating the MC1262 Thermal Battery Packs (fast-rise batteries) and MC1315 Sequential Timers (parachute timers).

2. MC1262 fast-rise batteries provide 12-volt power:

   a. T_0 contacts in MC1315 timers close.
   b. MC1315s initiate the MC1264 Thermal Batteries (main batteries).

3. 28-volt power is applied to contacts in the MC1268 Interval Timer.

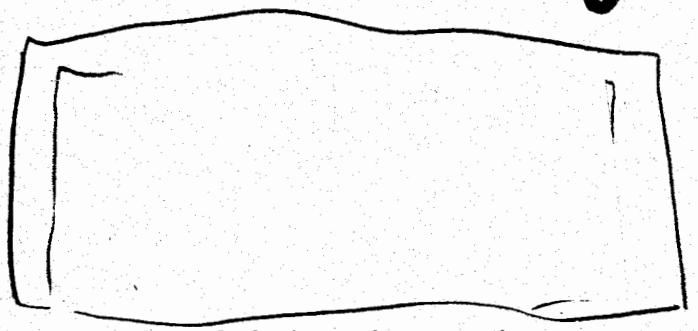
4. [redacted]

   a. MC1315 parachute timer contacts close, completing circuits between the MC1262 fast-rise batteries and the MC1060 Electric Detonators in the automatic parachute deployment system.
   b. MC1315 provides a signal to cut the retardation parachute suspension lines, and the parachute deployment sequence occurs.

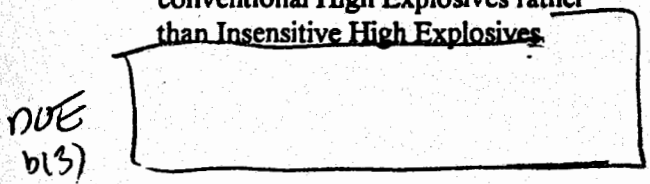
      (1) Automatic deployment cover is separated from the rear case section by mild detonating fuze (MDF) system.
      (2) Automatic deployment cover deploys the pilot parachute.
      (3) Pilot parachute deploys the retardation parachute.
      (4) [redacted]

      (5) [redacted]

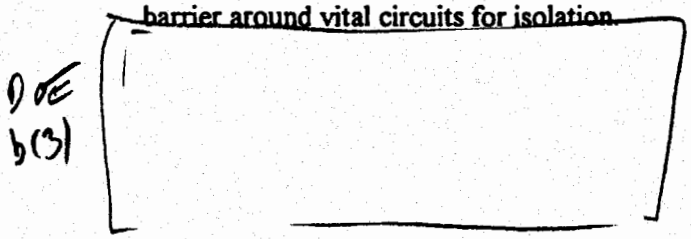
5. Laydown parachute drag causes the MC1268 Interval Timer (trajectory sensing device) to operate toward the armed position [redacted]



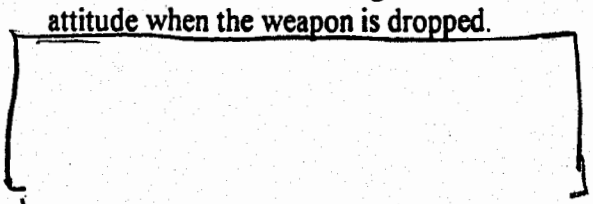
- The B53 physics package contains conventional High Explosives rather than Insensitive High Explosives.



- The B53 bomb was designed prior to the development of Enhanced Nuclear Detonation Safety (ENDS) concepts. The modification to the B53-1 utilizes a measure of ENDS, incorporating Power pack/shroud Zones and one hard-link (intent switch) and it does incorporate a barrier around vital circuits for isolation.



- The weapon contains an Environmental Sensing Device that is intended to block critical circuits until the intended use environment is sensed. The MC1268 interval timer senses a change in bomb attitude when the weapon is dropped.



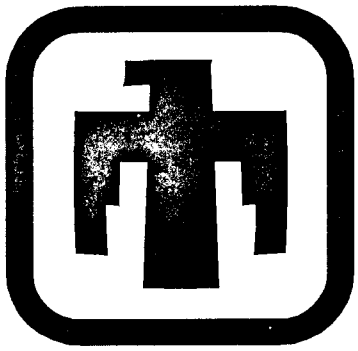
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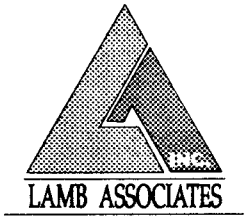
SITE SUMMARY FOR

STONY BROOK AIR FORCE STATION (AFS)
WESTOVER AIR RESERVE BASE (ARB)
CHICOPEE FALLS, MASSACHUSETTS

SANDIA NATIONAL LABORATORIES
JUNE 1995



Prepared by
Lamb Associates, Inc.



in conjunction with

Halliburton NUS
CORPORATION

Rev. 0



Bird cage photo taken at National Atomic Museum
October 2003 by Clarke Ketter

Note: This photo not in original Sandia Site Summary.

Building 941, the older of the two "A" Structures, was constructed as a massive concrete structure, containing only four small storage rooms. Each room is approximately 10 feet wide, 13 feet deep, and 9 feet high, with the capacity to accommodate up to 30 capsules in their "critically safe" storage containers. These storage rooms are accessed through bank vault-type doors with dual combination locks (Photo 7.4). Each vault contains 24 large cubicles, each of which are 36 inches across (Photo 7.5). Nuclear capsules stored too closely together in the "A" Structures could have achieved nuclear criticality, generating a burst of neutrons. Although the capsules would not have detonated, the burst of neutrons would have presented a health hazard to maintenance personnel. The storage containers for the nuclear capsules were designed to prevent any such criticality accident from occurring. Steel braces, welded to the top, bottom, and sides of the 14 inch by 25 inch cylinders created a frame of much larger volume than the cylinder and were designed to keep the capsules at a critically safe distance. The "bird cage," or finished container assemblies, were then sealed with lead-wire seals similar to those used to prevent tampering with electrical power meters, to ensure that their contents were not disturbed between authorized maintenance activities. A bird cage is shown in Photo 2.1.

Building 908, the newer "A" Structure, may have been built during expansion of the site in 1955 or 1956. The cubicles in Building 908, used for storing bird cages, are 30 inches across and allowed for storage of more capsules in each vault than did the older design. A vault door is located only at the entryway of the four-room area.

The false upper story of the "A" Structure, in reality a solid layer of concrete, disguises the purpose of the building. The ten-foot-thick walls and massive berming of the "A" Structures were primarily designed to shield capsules stored in the vaults from external attacks, as opposed to containing accidental detonations within the building. An explosion within the structure would have been unlikely, because a sophisticated external device was required to arm the capsules. The security provided confirms the strong procedural controls established both to protect the economic value of the material and to prevent its misuse. The stored material represented a significant portion of the United States Gross National Product in the early 1950s.

Nuclear component maintenance activities always took place in the "C" Structure, not in the "A" Structure where the devices were stored; thus, no nuclear material was ever exposed in the vaults. The potential for release of radioactive material occurred only within the "C" Structure. When scheduled maintenance of nuclear capsules was required at Stony Brook, two AEC personnel were dispatched to retrieve the capsules from the "A" Structure and deliver them to the "C" Structure. Occasionally, if two AEC personnel were not available, a SNL/NM supervisor would serve as the second required person to deliver or return the capsules.

Capsules were stored and transported in their critically-safe bird cages. The lead security seals were removed in the "C" Structure. After maintenance was completed, each capsule was replaced in its bird cage, sealed in its container, and returned by AEC personnel to its respective "A" Structure. The capsules were not kept overnight in the "C" Structures (Tucker, 1994). Building 941 is currently vacant; Building 908 is being used for records storage by MMWEC.

Listing of Pages Effective With Document Change #2

The following is a list of the page numbers and respective issue dates which are effective with Document Change #2 of this specification.

An issue date is not shown on any page of original issue.

Page No.	Issue Date	Page No.	Issue Date
1	Original	15	Original
1a	6-22-53	16	Original
2	Original	17	Original
3	Original	18	Original
4	Original	19	Original
5	Original	20	Original
6	Original	21	Original
7	Original	22	Original
8	Original	23	6-22-53
9	Original	24	Original
10	Original	25	Original
11	Original	26	Original
12	Original	27	6-11-53
13	Original	28	Original
14	Original	29	Original

Changes from previous issue are flagged with an asterisk in the right margin on each page.

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DEVELOPMENT SPECIFICATION
FOR
XMC-364

1 PURPOSE AND CLASSIFICATION

1.1 Purpose.--The XMC-364 is a modulated neutron source which is designed for use as an external initiator of implosion type weapons.

2 APPLICABLE SPECIFICATIONS AND OTHER PUBLICATIONS

2.1 Applicable Specifications. -- The following specifications of the issue and amendment designated (amendment number is given in parentheses after the specification designation) form a part of this specification to the extent indicated in the text and on the procuring agency drawings:

Federal Specifications		Custodian
QQ-P-416(1)	Plating, Cadmium (Electrodeposited)	Fed
QQ-S-571b	Solder, Soft (Tin,Tin-Lead,Lead-Silver)	Fed
QQ-Z-325	Zinc Plating (Electrodeposited)	Fed
QQ-S-561(Z)	Solder, Silver	Fed
TT-C-595(1)	Colors: (for) Ready Mixed Paints	Fed
TT-V-119	Varnish, Spar, Phenolic-Resin	Fed

2.1.2	Military Specifications	Custodian
MIL-E-1B	Electron Tubes	SIG & SH

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Custodian Symbol	Name of Custodian	Address of Custodian
USAF	Air Force	Commanding General Wright Air Development Center Attn: WCXSP Wright-Patterson Air Force Base Dayton, Ohio
A	Bureau of Aeronautics	Chief, Bureau of Aeronautics Technical Data Division Department of the Navy Washington, D.C.
FED	Federal	Superintendent of Documents U.S. Government Printing Office Washington 25, D.C.
O	Ordnance Corps	Office, Chief of Ordnance Washington 25, D.C.
SH	Bureau of Ships	Chief,Bureau of Ships Attn: Code 357 Department of the Navy Washington 25, D.C.
SC	Sandia Corporation	Sandia Corporation Attn: Purchasing Agent Sandia Base Albuquerque, New Mexico
SIG	Signal Corps	Commanding Officer Signal Corps Procurement Agency Attn: Technical Records Branch 2800 South 20th Street Philadelphia 45 Pennsylvania

3 REQUIREMENTS

3.1 Precedence

3.1.1 Precedence of this Specification and Related Documents. -- Whenever their requirements are in conflict, this specification and related documents shall take precedence in the following order:

a. The contract

b. This specification

c. Sandia Corporation drawings

d. Applicable specifications and standards

3.3.3 Fungus Inert Materials. -- Materials which are not nutrients for fungus shall be used to the greatest extent practicable.

3.3.3.1 Fungus-Nutrient Properties of Materials. -- The following materials are arranged in groups in the order of their resistance to fungus growth. Materials in Group Ia should be used in preference to those in Group Ib. Materials in Group II shall not be used unless their other desired properties cannot be obtained from materials in Group I. If materials in Group II are used, they shall be treated in accordance with 3.3.3.2. The use of materials other than those in Group I requires the prior written approval of the Sandia Corporation.

Group Ia

Ceramics
Glass
Glass-silicone
Melamines (except formaldehydes)
Metals
Mica
Monochlorotrifluorethylene
Nylon
Polyethylene (unplasticized)
Polymethylemthacrylate
Polystyrene
Polyvinylidiene chloride
Silicones (pure)

Group Ib

Cellulose acetate
Cellulose acetate butyrate
Diallylphthalate
Ethyl cellulose
Phenolics laminated with glass fibers or nylon
Phenolics (mica-,glass-, or asbestos-filled)
Phenolics (without fillers)
Polyvinyl chloride (Dioctylphthalate or dibutylphthalate plasticizers preferred)
Polyester resins
Rubber (synthetic and natural)

Group IIa

Cotton or linen cloth laminates
Phenolics filled with cotton fiber, wood or wood flour
Melamine formaldehyde
Vinyl acetate

Group IIb

Cellulose nitrate
Cork
Cotton webbing
Hair and wool felt
Leather
Paper
Regenerated cellulose
Wood and wood products

3.3.3.2 Fungus Resistant Treatments. -- If materials in Group IIa are used, they shall be coated with one coat of varnish per TT-V-119. If materials in Group IIb are used they shall be treated by a process approved by the Sandia Corporation.

3.3.4 Hygroscopic Materials. -- The water absorption characteristic of any materials used in the XMC-364 shall be the minimum for that class of material having the other desired characteristics.

3.3.4.1 Treatment of Hygroscopic Materials. -- Materials used in the XMC-364 which will absorb more than 1 per cent of their weight of water when tested in accordance with 4.2.9 shall have their surfaces coated with one coat of varnish, per TT-V-119. This requirement does not apply to insulation sleeving used on wire and cable.

3.3.4.2 Treatment of Machined Plastics. -- All machined surfaces of parts that are fabricated from plactics containing laminations or fillers, shall be coated with one coat of varnish, per TT-V-119.

3.3.5 Corrosion Resistance. -- All materials used shall be corrosion resistant or shall be treated to resist corrosion and shall cause a minimum of corrosion of other materials in the XMC-364 under the conditions specified in 3.8.

3.3.5.1 Additional Protection of Base Metals. -- Gold, nickel, chromium, rhodium, corrosion-resistant steel (12 per cent or more chromium), copper, tin, lead-tin alloys, or sufficiently thick platings of these metals are satisfactory without additional protection or treatment other than buffing or cleaning. In general, aluminum, magnesium, iron, steel, cadmium, and zinc require additional protection in accordance with 3.5.2.

3.3.5.2 Dissimilar Metals. -- Dissimilar metals shall not be used in contact unless suitably protected against electrolytic corrosion. When it is necessary that any combination of dissimilar metals be assembled, an interposing material compatible with each shall be used. Dissimilar metals are defined as follows:

a. Grouping of metals

Group I	Group II	Group III	Group IV
Magnesium alloys	Aluminum	Zinc	Copper and its alloys
	Aluminum alloys	Cadmium	Nickel and its alloys
	Zinc	Steel	Chromium
	Cadmium	Lead	Stainless steel
		Tin	Gold
			Silver

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3.5.7 Wiring

3.5.7.1 Hook-Up Wire: -- All hook-up wire shall conform to JAN-C-76, except as indicated by the responsible engineer of the Sandia Corporation. The size of wire shall be compatible with the electronic circuit in which it is used. No smaller wire than #22 shall be used without the approval of the responsible engineer. All special wires which are used in high current, video circuits shall be approved by the responsible engineer before being used.

3.5.7.2 Wire Connections. -- All wire ends shall be soldered at points of electrical connections and shall be mechanically secured before soldering, except when the small size of the wire or member to which the wire attaches makes a mechanically secured connection impractical, however such small mechanical connections shall be ample to hold the wire in place before soldering. Lugs or similar devices soldered to wire ends shall be used when electrical connections are made by clamping the conductor between parts. Such connections shall not be made by clamping wire ends between parts. Lugs or similar devices shall not be clamped between a metallic and an insulating material but shall be clamped between metallic members. Lugs of either the soldered or solderless type and similar devices may be used but shall be soldered to the wire ends and shall be mechanically secured to the wire by crimping the wire upon the terminal or the terminal upon the wire before soldering.

3.5.7.3 Insulation Hazards. -- Whenever wires are run through holes in metal partitions, shields and the like, less tha 1/8 inch in thickness, the holes shall be equipped with suitable grommets for mechanical protection of insulation otherwise subject to abrasion. Panels 1/8 inch or more in thickness either shall have grommets or shall have the hole edges rounded to a radius equal to one-half the thickness of the material or equal to the diameter of the largest wire running through the hole. Care shall be exercised in the running of hook-up wire to ensure that it is not carried over or bent around any sharp corner or edge which might in time cut through the insulation. In order to prevent deterioration of the conductor by heat, care shall be taken to ensure that wiring is not exposed to local temperatures and that it cannot come in direct contact with heated parts.

3.5.7.4 Interior Cabling. -- Conductors shall be bound into a cable whenever possible and securely held by means of wraplock, cord, or other suitable means. Cables shall be securely held in place by cable clamps.

3.5.7.5 Exterior Cabling. -- Cables used to interconnect equipment outside of enclosing cabinets shall be fabricated in accordance with SCS-4.

3.5.7.6 Coding. -- All wiring shall be distinctly coded by means of numbers on each end and color coded.

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3.6.6 Expected Life. -- The XMC-364 shall be capable of 46 operations in accordance with 4.2.1 without degradation of performance specified in 3.7 under the conditions of 3.8. Any of the first 45 operations may occur during or after the storage periods indicated in 3.8.3. The probability that the 46th operation shall be a malfunction shall not exceed 1 in 200 operations. The probability of malfunction occuring in any of the operations prior to the 46th operation shall also be 1 in 200 operations.

3.6.7 Safety. -- The XMC-364 shall be designed to provide maximum safety for maintenance and operating personnel. Adequate markings shall be located on equipment as warnings of mechanical, electrical, and nuclear radiation safety hazards as near the hazardous points as possible.

3.6.8 High Voltages. -- The XMC-364 or any of its components that is operative when separated from the XMC-364 shall either be designed so that operating or maintenance personnel cannot intentionally or accidentally contact voltages that are dangerous to life, or be suitably marked to warn personnel of the location of such voltages.

3.6.9 Convenience. -- The XMC-364 shall be designed to afford maximum accessibility for the replacement, adjustment and testing of its components without the necessity for disconnecting or removing interposed electrical or mechanical parts.

3.6.10 Interference. -- The XMC-364 shall comply with the requirements of MIL-I-6181 governing generation of and susceptibility to radio frequency interference voltages and fields.

3.7 Performance Requirements

3.7.1 Primary Power

a. The XMC-364 shall operate from a 400 cps ± 5 per cent power source at 115-v ± 10 per cent.

b. The XMC-364 shall operate to its intended use, in any position after a 30 second warm up period. The XMC-364 power load shall not exceed 140 watts except during short surges. Two such short surges shall be allowed in a 30 second period; the time between surges shall be a minimum of 10 seconds. A short surge shall not exceed 225 watts peak and its duration shall not exceed 3 seconds before falling off to one half of the peak of the surge. Power as a function of time requirements are shown in Figure 1. At time A the XMC-364 is turned on; at time B auxiliary equipment used with the XMC-364 is turned on. Time B shall occur at least 5 seconds before time C. The XMC-364 shall operate to its intended use after time C. Time B shall follow time A by a minimum of 10 seconds.

c. No fuses shall be used in the primary power circuit for protective purposes.

d. The XMC-364 shall not malfunction or operate prematurely to its intended use in accordance with 1.1 from signals generated in the primary power supply.

e. A regulator is required to maintain the specified voltage. The voltage regulator shall be capable of the output requirements as given in Figure 1. Regulation during short surges is not required to the accuracy indicated in (a) above. The output voltage of the regulator will nominally be 90 volts ± 1 per cent. All circuits in the XMC-364 which operate directly from the AC power supply shall be designed for 90 volts ± 1 per cent input.

f. The intended use of the XMC-364 shall be in accordance with 1.1. The performance of the XMC-364 shall be tested either by the initiation of a nuclear weapon, or by a measuring device which indicates the proper magnitude of the neutron yield at the proper time.

3.7.2 Output Intensity. -- The XMC-364 neutron yield and timing requirements are specified as follows:

DOE
b(3)

3.7.3 Operation. -- The XMC-364 shall be capable of the specified output when the following signals are supplied to the XMC-364 and when the following conditions exist in the XMC-364.

3.7.3.1 Initial Signal. -- The XMC-364 including the precision timer shall be capable of the specified output 30 seconds after the primary power is available and after being supplied by a suitable pulse. The initial signal shall be an electronic device which generates signals of the form shown in DS(5330)24289. One of these signals shall be used as the initial pulse. The initial pulse shall be reshaped for use as required. The initial signal shall have the following characteristics:

a. The amplitude of the initial signal shall be a minimum of 300 volts and a maximum of 750 volts.

b. The rise time of the initial signal shall be a maximum of .05 microseconds. The rise time of the signal is the time required for the amplitude of the signal to increase from 0.1 to 0.9 of its maximum value.

c. The maximum length of the pulse shall be 30 microseconds and the minimum length shall be 0.5 microseconds. The pulse length is the time interval between the two 0.1 maximum value points of the signal.

d. The output impedance of the signal generator shall not exceed 2500 ohms. A signal of less than 10-v peak amplitude shall not initiate the operating cycle of the XMC-364.

3.7.3.2 Precision Timer. -- The initial signal shall start a precision

DOE 6(3)

3.7.3.3 Source Gap Circuit. -- Upon receipt of the delayed signal from the precision timer, a 0.015 microfarad capacitor which has been charged to 17 kv ± 3 per cent shall be discharged into the source of the accelerator tube. This energy produces ions in the vicinity of the source. The discharge shall be initiated by a spark-gap.

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3.7.3.4 Target Pulse Delay. -- The delayed signal from the precision timer shall be delayed so that maximum yield from the XMC-364 results, and this delayed signal shall be used to fire the target spark-gap.

DOE 6(3)

delay does not include the target spark-gap delay.

3.7.3.5 Target Pulse Generator. -- Upon receipt of the delayed signal in 3.7.3.4, a 0.21 ± .03 microfarad capacitance which has been charged to 17 kv ± 3 per cent shall be discharged into the primary of a step-up pulse transformer. The output of the pulse transformer shall be such that the neutron yield in 3.7.2 is obtained. The capacitor is discharged by a spark-gap.

3.7.4 XMC-364 Components. -- The XMC-364 shall consist of the following major components.

3.7.4.1 Voltage Regulator. -- The input to the voltage regulator shall be obtained for a power supply which is capable of supplying the required power as specified in 3.7.1. The voltage regulator shall supply 90-v RMS at 400 cps ± 5 per cent with a maximum variation in voltage of ± 1 per cent. The voltage regulator shall also supply peak regulated power which is proportional to the RMS power. The power supplied shall be as follows:

1. 90-v RMS - 100 watts

2. 90-v Peak - 40 watts

The time required for the voltage regulator to smooth a stop load of 50 watts shall be a maximum of 2 seconds. The voltage regulator shall be capable of the specified output up to and after 90 days storage with no adjustments made when the regulator is removed from storage.

3.7.4.2 High Voltage Power Supply. -- The input to the high voltage power supply shall be obtained from the voltage regulator. The input shall be:

90-v peak proportional to RMS and 90-v RMS AC ± 1 per cent, 400 cycle ± 5 per cent.

The output voltage shall be used to charge the source capacitor and the target capacitor. The target capacitor, which is .21 microfarad ± 0.05 microfarad, shall be charged to a minimum of 16,500-v and a maximum of 17,500-v. The voltage shall not vary more than ± 1 per cent when set between these limits. The target capacitor shall charge to within 98 per cent of the set voltage in a maximum of 10 seconds. The maximum charging current shall be 6 ma. The source capacitor which is a .015 microfarad ± .005 microfarad shall charge to a minimum of 16,500-v and a maximum of 17,500-v. The voltage shall not vary ± 1.0 per cent when set between these limits. The source capacitor shall charge to within 98 per cent of the set voltage in a maximum of 10 seconds. 5 kv RMS ± 10 per cent at 500 microamperes shall be supplied to the accelerator tube's modified Phillips Ion Gage.

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3.7.4.3 Low Voltage Power Supply

3.7.4.3.1 Input. -- 90-v ± 1 per cent RMS AC, 400 cycle ± 5 per cent.

3.7.4.3.2 Output. -- The output shall include all regulated DC voltages to the precision timer, the voltage regulator, and the trigger circuits in the source gap. The voltage shall be as follows:

+ 500 volts unregulated	10 milliamperes
+ 300 volts regulated	75 milliamperes -1 per cent regulated
- 105 volts regulated	10 milliamperes - VR tube regulated

The filament power for all tubes in the XMC-364 will be obtained from a 6.3-v, 10 ampere source.

3.7.4.4 Source-Gap Circuits. -- The source-gap circuit shall include:

a. Source capacitor of 0.015 ± .005 microfarads

b. Source spark-gap

c. Source spark-gap trigger, trigger transformer

The source-gap circuit shall be in accordance with drawing DS(5330)24288.

3.7.4.5 Target Pulse Delay. -- The function of the target pulse delay is given in 3.7.3.4. The target pulse delay circuit shall be in accordance with drawing DS(5330)24288.

3.7.4.6 Target Gap Circuit. -- The target gap circuit shall consist of:

a. A 0.21 ± .05 microfarad capacitor which is charged to 17 kv ± 3 per cent negative with respect to ground.

b. A target spark-gap which when triggered discharges to 0.21 microfarad capacitor in (a).

c. A spark-gap trigger transformer which when supplied with a pulse triggers the spark-gap in (b).

DOE b(3)

3.7.4.7 Precision Timer. -- The precision timer specifications shall be in accordance with SC-5107-Sp.

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4.2.4 Humidity Test

4.2.4.1 Preconditioning. -- The XMC-364 shall be placed in a chamber which has been preheated to 130°F and has a relative humidity of 15 per cent. The XMC-364 shall remain in the chamber for a period of 24 hours. Immediately upon withdrawal the XMC-364 shall be placed in a suitable humidity chamber and subjected to five humidity cycles in accordance with 4.2.4.2.

4.2.4.2 Humidity Cycle. -- While the XMC-364 is in the chamber, the humidity shall be maintained at 90 to 98 per cent relative humidity throughout the following cycle:

a. The temperature shall be raised to 149°F within 4 hours and maintained at this point for 8 hours.

b. The temperature shall then be reduced to 86°F within 4 hours and maintained at this point for 21 hours. Between the 8th and 12th hours after stabilization at 86°F, the XMC-364 shall meet the requirements of 4.3.1.

c. The temperature shall be reduced to 68°F within one hour and maintained at this point for 4 hours.

d. The temperature shall then be raised to 86°F within one hour and maintained at this point for 5 hours.

4.2.4.3 Inspection Following Test. -- Upon completion of the humidity test, the XMC-364 shall meet the requirements of 4.2.1. Parts thereof shall be inspected for deterioration of materials, such as corrosion and water absorption, or potential deterioration because of accumulation of moisture.

4.2.5 Salt Spray. -- The XMC-364 shall be tested in a salt spray chamber in accordance with MIL-E-5272, Section 4.6 for 50 hours. Upon completion of the test the assembly shall meet the requirements of 4.2.1 and shall be visually inspected for deterioration of materials, e.g., corrosion.

4.2.6 Dust and Sand. -- The XMC-364 shall be tested in a dust chamber in accordance with MIL-E-5272, Section 4.11, Procedure I. Upon completion of the test the XMC-364 shall meet the requirements of 4.2.1.

4.2.7 Vibration

4.2.7.1 Resonant Frequencies. -- Prior to the vibration tests specified herein, the mechanical resonant frequencies of the assembly and/or its components shall be determined by cycling through the frequency ranges of 10 to 60 to 10 cps and 60 to 500 to 60 cps at low amplitude. If any serious resonant conditions (as evidenced by extreme amplitudes) are detected, the assembly and/or its components shall be redesigned to eliminate or minimize resonance. Prior to redesign the Sandia Corporation shall be consulted. Upon the written approval of the Sandia Corporation, vibration isolators (e.g., shock mounts) may be used.

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4.2.7.2 Equipment Operating/Nonoperating Tests. -- The complete assembly (with its approved vibration isolators if any) shall be secured to a vibration table in the manner it will be mounted in service, and shall be vibrated in each of three mutually perpendicular planes under the following test conditions:

Condition	Frequency range(cps)	Constant Acceleration or double amplitude (g or inches)	Duration of cycle (minutes)	Duration of test (minutes)
1	3-10-3	.098	5	25
2	10-30-10	.109	5	25
3	30-60-30	.054	15	25
4	60-500-60	10 g	15	45

The assembly shall meet the requirements of 4.2.1 during the last few minutes of vibration under each condition in each of three planes.

4.2.8 Acceleration and Shock

4.2.8.1 Acceleration. -- The assembly shall be mounted on a spin table and subjected to a constant acceleration of 50 g for at least one second applied in both the fore and aft directions. The fore and aft line is defined by the mounting arrangement of the assembly with respect to and is parallel to the line of forward motion of the carrying vehicle. The assembly shall meet the requirements of 4.2.1 during the acceleration period.

4.2.8.2 Shock. -- The assembly shall be dropped 5 times from a height such as to produce an acceleration of 30 g in 11 ± 1 milliseconds in accordance with Figure 5 of USAF 7201. The assembly shall meet the requirements of 4.2.1 after this test.

4.2.9 Water Absorption Test. -- Materials which may absorb water shall be tested to determine the necessity of treatment in accordance with 3.3.4.1. Test strips of the material 1/8 inch thick 1 inch wide and 3 inches long shall be dried in an oven at 90°F for 24 hours. They shall then be immersed in water for a period of 24 hours. The strips shall be removed from the water, wiped dry, and immediately weighed. This weight shall be compared with the weight of the predried sample before immersion to obtain the water absorption characteristic (in per cent).

4.2.10 Rain Test. -- The assembly shall be tested in accordance with MIL-E-5272, Section 4.10.1. Upon completion of the test, the assembly shall meet the requirements of 4.2.1.

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5 PREPARATION FOR DELIVERY

5.1 Packaging. -- The XMC-364 shall be packaged to prevent damage in shipment by common carrier and ensure delivery in such a condition as to conform with all the requirements of this specification.

5.2 Marking. -- Each package shall be marked 'FRAGILE-HANDLE WITH CARE'.

6 NOTES

None

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INVENTORIED MAR 1 1966

MAR 1965 3428-3

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AUG 1 1962

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DOE 6(3)

INVENTORIED

MAY 22 1957

BY ORG. 2743

A PROPOSED ZIPPER SYSTEM FOR SMALL WEAPONS (U)

B. J. Carr - 1423

ABSTRACT

The unit should be no larger than 100 cubic inches in volume and should weigh about 10 pounds. Two units, in a dual system, could be placed in an 11-1/2-inch-OD space only 3-1/2 inches thick.

Power and trigger can be supplied from an X-unit, or other 28-volt DC input supplies such as rotary choppers and transverters can be used.

A look into other possible future Zipper units of considerably smaller dimensions is discussed.

Work performed under AEC Contract AT-(29-1)-789.

Inventoried September 1960

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Case No. 755.00

April 12, 1957

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A PROPOSED ZIPPER SYSTEM FOR SMALL WEAPONS

INTRODUCTION

With the realization of the desires for smaller nuclear warhead systems, it has become necessary to consider smaller Zipper units. DOE b(3)

A Zipper system which shows promise for these applications is described herein. DOE b(3)

The time delay is included in the system which is small and rugged; depending upon the power supply and timer unit selected, the system is capable of being relatively radiation-resistant.

REQUIREMENTS

A summary of the controlling requirements for this system analysis follows:

Applications

This Zipper is intended for use in 10- to 12-inch-small warheads used in guided missiles (NIKE AJAX, TERRIER, and possibly air-to-air missiles), a ballistic missile (LITTLE JOHN), a (high-g) rocket-assisted depth bomb (ASROC), and an atomic demolition munition (C-ADM). DOE b(3)

The criteria listed below include present information as to the extreme requirements which will be imposed on the Zipper by the above applications. Development of a miniaturized version of the XMC-825 with choice of power supplies such as a rotary-chopper converter, transverter or X-unit voltage supply may prove satisfactory.

Performance Requirements

Electrical. -- Zipper units should be capable of accepting a 28±4-volt DC, 1-ampere or less per channel power input, or X-unit voltages of 1800 to 2600 volts DC so that it will operate in 4 seconds after application of this power by triggering from an X-unit or other suitable signal.

DOE b(3)

. Actual neutron requirements are not firm and will be obtained from the nuclear laboratories when they have been definitely determined.

DOE b(3)

Environmental. -- The Zipper should be environmentally compatible with SCS-7 with the addition of the ability to withstand the following criteria.

-- Operate after the following weapon environments:

Linear Accelerations - 2000 g's for 0.1 ms,
1000 g's for 2 ms,
650 g's for 0.5 sec,
500-g shock in any direction.

-- Operate after the following weapon environments:

Linear Accelerations - 2000 g's for 0.1 ms,
1500 g's for 2 ms,
500-g shock in any direction.

-- Operate after the following weapon environments:

Linear Accelerations - 75 g's for 4.5 sec,
Angular Acceleration - 2000 rad/sec/sec for 0.01 sec.

Angular Velocity - 50 rad/sec for 100 sec.

Altitude - Operation at 90,000 feet altitude is required.

DOE b(3)

If extreme difficulty is encountered in development due to the acceleration, radiation insensitivity, and size and weight requirements, two separate Zipper developments might best be considered with less restrictive radiation, weight and size requirements on the high-g unit.

Reliability. -- Failure probability of a single-channel system not to exceed 1/100.

Dimensional Requirements

Size and Shape. -- Dual-channel unit allowable volume appears to be approximately 200 cubic inches. Actual size and packaging configuration should be coordinated with the applicable 1200 or 1800 project group, and appropriate form factors will have to be negotiated as design progresses.

Weight. -- Because of warhead application requirements, the weight of a dual-channel Zipper should be limited to 20 pounds including potting, with a lower weight preferred.

Additional information which may be of aid during the development stages of the Zipper unit follows:

Time Scales

Weapon Operational Availability. --

DOE b(3)

October 1959 (Other Applications)

Component CDR Desired

DOE 6(3)

June 1958 (Other Applications)

Development Models Required

DOE 1(3)

September 1957 (Other Applications)

Cognizant 1000 Organizations

DOE 6(3)

Systems	Project
1261	1225
1261	1222
1261	1810
1261	1810

SYSTEMS

Figure 1

The basic system considered herein is shown in block diagram form in Figure 1. The pulsed neutron source is the same small pulsed linear accelerator which has been developed for other weapon applications. DOE 6(3)

Energy for these pulses is stored in a capacitor similar to those being developed for X-units. The energy is switched to the transformer by a switch which is triggered by the output of the timer unit. The timer itself may be electronic or explosive in nature. The input to the timer may be obtained from several points in the weapon system as may be found most adequate, such as the

FIG. 1 NEUTRON SOURCE SYSTEM BLOCK DIAGRAM

X-unit load plate, X-unit capacitor plate, an X-unit fired detonator or a crystal signal derived from the exploding HE of the nuclear system.

Power to charge the energy storage capacitor may be chosen for each specific application as desired, but the primary requirement is that the energy storage capacitor be charged to from 1800 to 2600 volts DC. Investigations will be carried out to determine if the 1800-volt minimum is realistic if its occurrence is small. Since the electronic timer delay circuit can be made so that the time delay is a function of the input voltage, there are several advantages to using voltages equal to that on the X-unit capacitor for the Zipper-operating voltage. In the case of an explosive timer, this advantage is small, and where an electronic timer with a crystal input is used, the advantages and disadvantages are not clear.

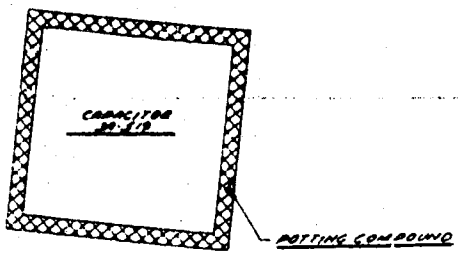
Three possible circuits for the Zipper system are shown in Figures 2, 3, and 4. The similarity of each of these circuits is that the energy storage, pulse transformer for accelerating potentials, and the neutron source tube are identical. The timers and high-voltage switch are different. Both the circuits in Figure 2 and Figure 3 are capable of several tests with no appreciable degradation to the system. The circuit in Figure 4 is a one-shot device, but special laboratory equipment can be devised which would permit the pulsed neutron portion of the unit to be tested. This unit is probably the most reliable circuit shown because it essentially precludes any field tests which might degrade its operation.

Figure 2

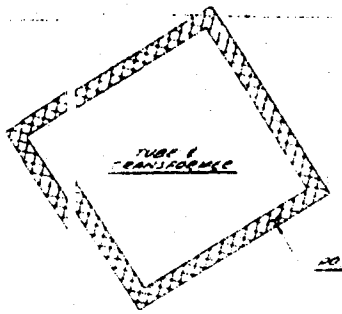
The time delay unit shown in Figure 2 uses an electronic timer. The time delay circuit input signal is derived from the X-unit capacitor plate.

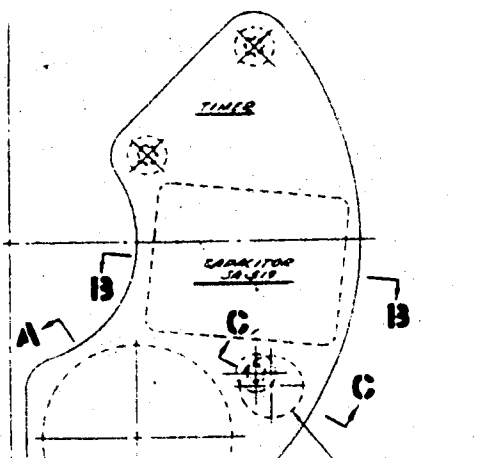
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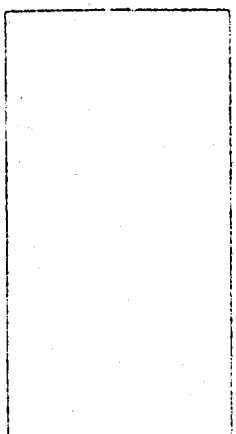
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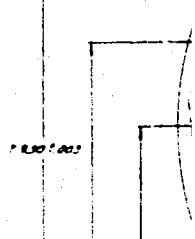
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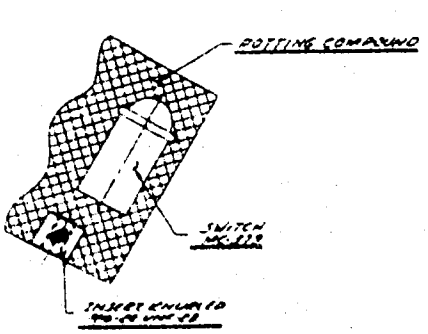






SECTION A-A

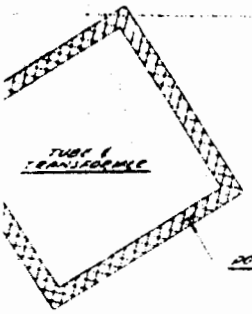




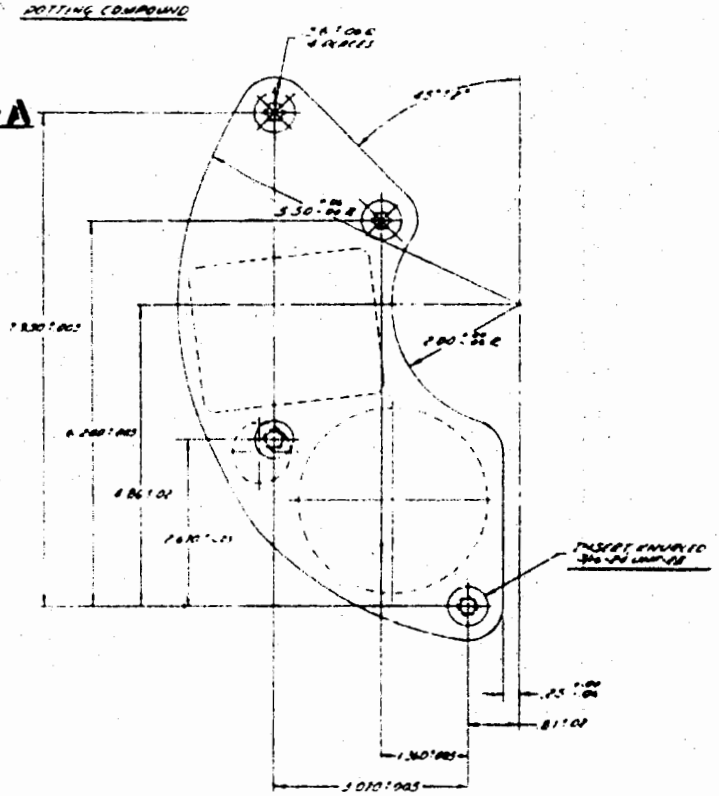
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NOTES



SECTION A-A



LIST OF MATERIAL

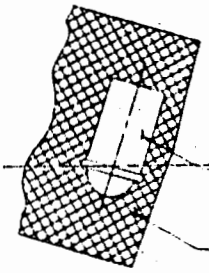
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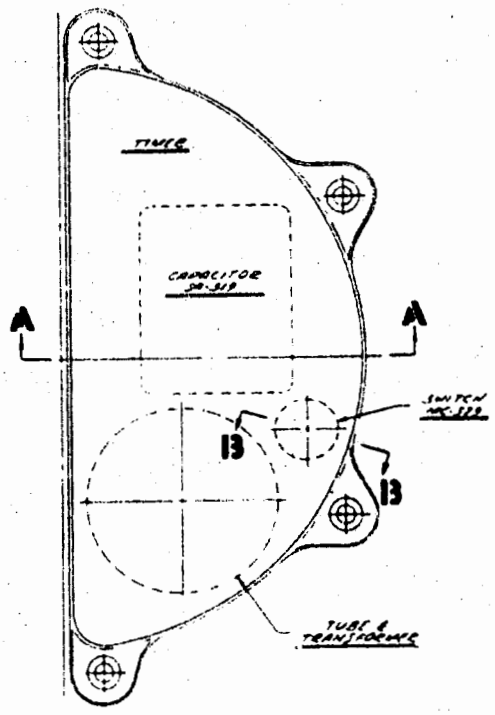
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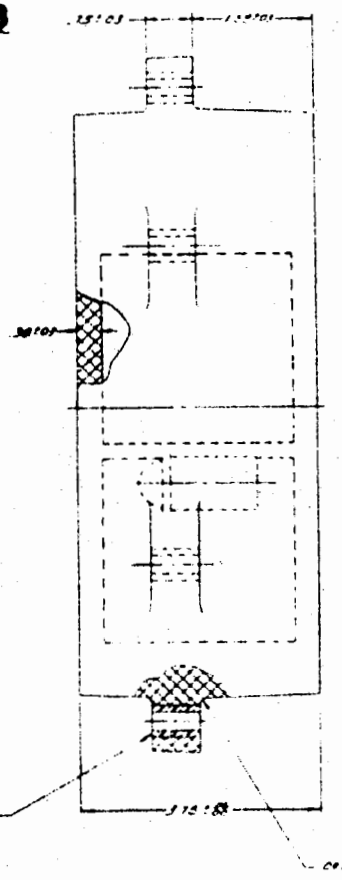
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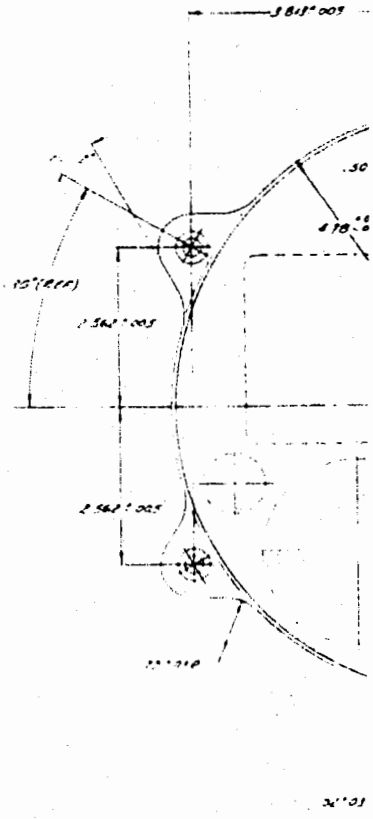
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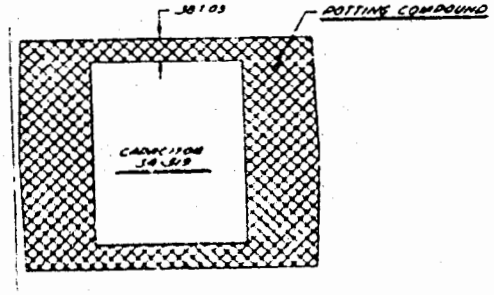


SECTION B-B



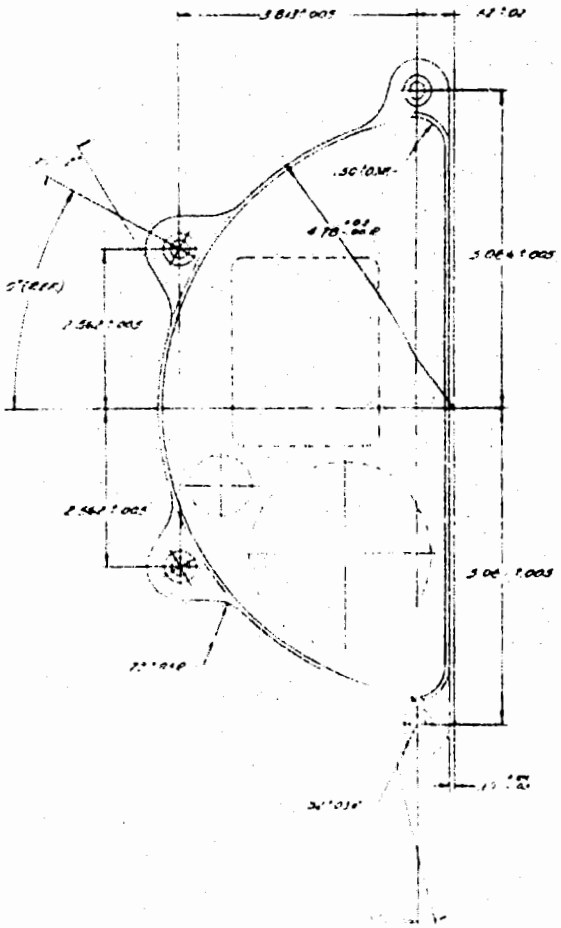






SECTION A-A

NOTES



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STATUS OF DEVELOPMENT

Neutron Source Tube

DOE b(3)

They are 1-1/4 inches OD x 1-3/4 inches long and 1 inch OD and 1-3/4 inches long. Research on size requirements is being studied at UCRL (Berkeley) and at GEXR. The General Electric X-Ray Department is required to furnish breadboard units in April 1957, and will develop a suitable tube and unit for these applications.

A PIG is not desirable and efforts will be directed to removing it from the tube. The initial tube models do not use PIG's.

One transformer of the size required for these applications has been tested in oil. Considerable development of this part is necessary.

The timer circuit shown in Figure 2 has been built in breadboard form and has been tested. Preliminary data from HE experts have been found indicating that the probable accuracy of the HE timer is acceptable.

A modified SA-519 capacitor is planned for use as the energy-storage capacitor. Power supplies for use at 28 volts DC are being developed in Divisions 1469 and 1472.

A high-current, low trigger voltage cold-cathode tube is being developed in 1450. The tube is also being ruggedized to withstand high accelerations.

DOE b(3)

POSSIBLE FUTURE SYSTEMS

On a considerably longer time scale, a system which does not require a separate power supply may be practical. Possible systems are shown in

Figure 8. Here again a pulsed neutron source tube is used but energy and time delay are obtained from high explosives. Energy is transduced to usable voltage and currents by $B_aT_iO_3$ or PZT crystals and ferroelectric materials. The system operation is initiated by either an X-unit detonator or the explosive in the HE space chamber. Also possible, but more in the future, would be a system in which the HE shown in Figure 8 is the HE in the nuclear system. 1 DOE b(3)

They should be quite small, perhaps so small as 20 cubic inches for a unit. In addition, increased reliability due to decreased complexity might permit the use of a single unit in the weapons.

CONCLUSIONS

Since the time scales involved in systems such as XW-35, etc., are short, it is necessary that existing technology be capitalized upon to as great an extent as possible. Any of the systems proposed in some detail in this report require some development but the system shown in Figure 2 perhaps changes the developed art the least amount and presents at least reasonably small size and sufficiently high reliability possibilities. On the other hand, if radiation problems ruin the diodes in the proposed electronic timers, the explosive time delay system in Figure 4 may be the only usable solution. Its advantages make its use desirable but this system requires more development than the two systems using electronic timers. Subsequent to a good understanding for the radiation problem, it appears advisable to exert considerable effort on the explosive time delay system as a backup to an electronic timer.

The size of Zipper units shall be further decreased, but the proposed sizes look promising for use in near-future applications--11- to 12-inch weapons.

[redacted] DOE b(3)

. The major problems in size will be related to dielectric strength of materials to protect the circuits from voltage breakdown since the tube should be developed toward a one-shot capability. This would lower the tritium in the tube to an extremely small amount so that the PIG may not be necessary. Tube efficiency should also be increased by lowering secondary emission from the target.

B. J. CARR - 1423

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Report written:
January 1954

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WEAPONS ACTIVITIES
of
LOS ALAMOS SCIENTIFIC LABORATORY
PART I (U)

by
Samuel Glasstone

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FOREWORD

This report is an ambitious attempt to summarize weapons activities at Los Alamos Scientific Laboratory in a reasonably short and concise volume for the reference of staff members of the Laboratory and certain key representatives of the Armed Forces and the Atomic Energy Commission. Weapons activities here, as is well known, cover a large field with few defined boundaries. Its ramifications have led into many by-paths and it would be impossible, of course, to detail all the work which has been undertaken during the past eleven years. Moreover, the report, although it embraces the whole period of nuclear weapons development at the Laboratory, does not take the historical approach. That is, it does not chronologically define all the designs evolved and the development steps taken to achieve the end product of all Mark weapons. Its aim has been rather to elucidate as concisely as possible the underlying principles of nuclear weapons as they have been applied and empirically tested during their developmental process. It does not contain a detailed discussion of the mathematical analyses of the technological developments, engineering applications and shop construction expended upon primary models. The report is therefore neither a history of development nor a technical guide for designing nuclear weapons.

As a basic handbook on the principles of nuclear weapons development, this report should fill a variety of needs. It is recommended particularly to the attention of new staff members of the Laboratory, and for the reference use of members of the staff of the Department of Defense and the AEC who have often expressed a need for an exposition of the complex and diversified work which the Laboratory has undertaken in the interests of our national defense and security.

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ACKNOWLEDGEMENT

The preparation of this report has required the coverage of both considerable range and depth of technical detail. The work could not have been completed, especially in the time available, without the generous cooperation of many members of the Laboratory staff. It is impossible to mention the names of all who contributed in one way or another, but their invaluable help is gratefully acknowledged.

In the course of collecting material, I have been greatly impressed by the excellent morale and enthusiasm that prevail throughout the Laboratory. The general scientific atmosphere is undoubtedly responsible for the important progress in weapons development summarized here. In addition, it has made the preparation of this report a pleasure and a privilege.

Samuel Glasstone

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Chapter 1

Principles of Nuclear Energy Production

1.1 Release of Nuclear Energy

Fission and Fusion

Any nuclear reaction in which there is a net decrease of mass, i.e., in which the total mass of the products is less than that of the interacting particles, will be accompanied by a liberation of energy. Two types of reaction have been used for the large-scale release of nuclear energy. These are (a) fission, i.e., the splitting of a heavy nucleus into a pair of lighter nuclei, and (b) fusion, i.e., the combination of two very light nuclei to form a somewhat heavier one. The underlying reason why these processes are accompanied by a decrease of mass and, hence, a liberation of energy is that in each case the average net energy of attraction between the nuclear particles, i.e., the protons and neutrons, often referred to as nucleons, is smaller in the initial nucleus (or nuclei) than it is in the products of the reaction.

Mass Defect and Binding Energy

The magnitude of the net attractive energy, or binding energy, of the nucleons in any nucleus can be calculated from the masses of the various particles. Consider an isotope of mass number A and atomic number Z, so that the nucleus contains Z protons and A - Z neutrons. If m_p is the mass of a proton, m_n is the mass of a neutron, and M is the actual mass of the nucleus, as determined by the mass spectrograph or other nuclear measurements, then the mass defect (M.D.) of the particular isotope is defined by

$$\text{M.D.} = \left[Zm_p + (A - Z)m_n\right] - M. \qquad (1.1)$$

The mass defect, which may be regarded as the decrease of mass that would result if Z protons and A - Z neutrons were combined to form a given nucleus, is a measure of the binding energy of that nucleus.

Binding Energy

If the various masses are expressed in the familiar atomic mass units (amu), in which m_p is 1.00813 and m_n is 1.00897, then multiplication of M.D. by 931 gives the binding energy (B.E.) in million electron volts (Mev). This factor is based on the Einstein mass energy equation using the appropriate units of mass (amu) and energy (Mev). Consequently,

$$\text{B.E.} = 931 \left\{\left[Zm_p + (A - Z)m_n\right] - M\right\} \text{ Mev.} \qquad (1.2)$$

This gives the energy which would be released in the formation of a nucleus by the combination of the appropriate protons and neutrons or, alternatively, the energy which would be necessary to break up the nucleus into its constituent protons and neutrons.

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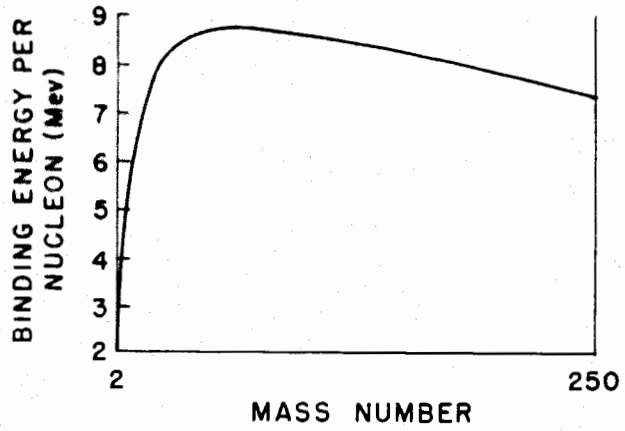


Fig. 1.1

A useful quantity is the mean binding energy per nucleon, i.e., B.E./A, where the mass number, A, is the number of protons and neutrons in the nucleus. The values of B.E./A for many nuclear species have been determined, from their known masses, and when plotted against the respective mass numbers, as in Fig. 1.1, the results are found to fall on, or very close to, a continuous curve. The significant aspect of this curve, for the present purpose, is that the mean binding energy per nucleon is less for the lightest and for the heaviest nuclei than it is for those of intermediate mass. It is this fact which accounts for the liberation of energy accompanying either the fission of heavy nuclei or the fusion of light nuclei, as can be shown in the following manner.

Calculation of Fission Energy

Uranium-235 undergoes fission in some thirty or more different ways, i.e., many different pairs of nuclei are formed. In the great majority of cases, however, the mass numbers of the fission products lie within the range from about 80 to 150, and from Fig. 1.1 it is seen that the average value of the binding energy per nucleon in this region is about 8.4 Mev. On the other hand, in the original uranium-235, the binding energy per nucleon is 7.5 Mev. Hence, the total energy which would be required to break up a uranium-235 nucleus into its 235 constituent nucleons would be 235 x 7.5 Mev, whereas for the fission product nuclei the corresponding energy would be about 235 x 8.4 Mev. In this calculation the neutrons involved in fission are neglected for simplicity, since they will have little effect on the final result. Consequently,

$$\text{Uranium-235} + (235 \times 7.5)\text{Mev} \longrightarrow 235 \text{ nucleons}$$
$$\text{Fission products} + (235 \times 8.4)\text{Mev} \longrightarrow 235 \text{ nucleons}$$

and upon subtraction and rearrangement it is seen that

$$\text{Uranium-235} \longrightarrow \text{Fission products} + (235 \times 0.9)\text{Mev}.$$

In other words, the fission of uranium-235 is accompanied by the release of 235 x 0.9 Mev, i.e., about 200 Mev, of energy.

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It can be shown in an exactly analogous manner than the fusion of very light nuclei, in particular those of hydrogen and its isotopes, i.e., deuterium (D) and tritium (T), is associated with the liberation of energy, because of the difference in the mean binding energies. This is exactly the same as saying, as indicated earlier, that the mass of the products is less than that of the interacting nuclei. The difference in mass appears as energy, in accordance with the mass-energy equivalence relationship.

The Fission Process

Although fission of heavy nuclei can be brought about in a number of ways, there is only one that is of importance for the practical release of nuclear energy: this is fission initiated by neutrons. The reason is that the fission process is itself accompanied by the liberation of neutrons, so that a chain reaction with the continuous release of energy is possible. Only three isotopes, namely, uranium-233, uranium-235, and plutonium-239, need be considered here for use in a fission chain process. In the first place, although these substances are radioactive, they have relatively long half lives, so that they may be regarded as moderately stable. And, in the second place, they will undergo fission by the capture of neutrons of all energies, i.e., either fast (high energy) or slow (low energy).

The common isotope uranium-238 requires neutrons of at least 1 Mev energy to cause fission. Although most of the neutrons produced in fission actually have higher energies, they rapidly lose energy in collisions, so that they are brought below the threshold of 1 Mev for fission of uranium-238. Consequently, the maintenance of a chain reaction in uranium-238, is not possible. Nevertheless, fission of this isotope does occur and the energy released often makes an appreciable contribution to the total energy produced in nuclear weapons.

Of the three fissionable (or fissile) species mentioned above, only uranium-235 and plutonium-239 have hitherto been used in nuclear weapons. The amount of uranium-233 at present available is too small for this purpose, although it may become of considerable importance in the future. However, the general discussion of the fission chain process to be given here applies equally to all three isotopes. Such differences in behavior as do exist arise from a difference in the average number of neutrons produced when fission occurs and in the relative importance of fission and nonfission reactions.

The fission process may be regarded as producing three types of products: (a) lighter nuclei, called fission fragments, (b) neutrons, referred to as fission neutrons, and (c) energy. Thus, taking uranium-235 as typical, the fission act may be represented by

$$\text{Uranium-235} + n \longrightarrow \text{Fission fragments} + 2\text{-}3 \text{ neutrons} + \text{energy}.$$

These products will be considered in turn.

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Fission Products

Some 60 or so different isotopes (fission fragments) are formed in fission, corresponding to the 30 or so different ways in which the heavy nuclei can split up into two lighter nuclei. Most of the fragments are radioactive, emitting beta and gamma radiations. On the average, each fission fragment undergoes three stages of beta decay before attaining stability, so that there are ultimately formed about 200 different isotopic species, most of which are radioactive. The mixture of fission fragments and their decay products is referred to by the general name of fission products. As just indicated, it is a very complex system, containing many radioisotopes, with half lives ranging from a small fraction of a second to a million years.

Fission Neutrons

The number of neutrons produced in fission varies somewhat with the different modes in which the nucleus splits, but the average number of fission neutrons (ν) is well defined. The results of experimental measurements are given in Table 1.1 for the three important fissile species. It should be noted that the number of fission neutrons produced by plutonium-239 is appreciably greater than that released by uranium-235. This has an important bearing on the design of atomic weapons. The energies of fission neutrons range from quite small values up to 14 Mev or more, the majority having energies of about 1 to 2 Mev.

Table 1.1 Average Numbers of Fission Neutrons*

Uranium-235	2.51
Plutonium-239	2.96
Uranium-233	2.60

The neutrons emitted in fission can be divided into two categories, namely, prompt neutrons and delayed neutrons. The former are all released within something like 10^{-12} sec of the fission process, but the latter continue for several minutes. For uranium-235 fission the prompt neutrons constitute 99.25 per cent of the total fission neutrons and for plutonium-239 they represent 99.75 per cent. Because the time scale in a nuclear explosion is very short, delayed neutrons play essentially no part in the reactions. Nevertheless, they are of great significance in connection with reactors (or "piles") in which the energy release is controlled, so that the fission rate is relatively slow.

Fission Energy

The rough calculation given earlier indicated that about 200 Mev are produced in each act of fission. Actually, both experimental measurements and more precise calculations, based on accurate values of the masses of the nuclei involved, have shown this to be a fair approximation

* Strictly true only when fission is initiated by fission spectrum neutrons.

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for both uranium-235 and plutonium-239. On the basis of this figure, of 200 Mev per fission, the energy theoretically available from the complete fission of 1 kilogram (2.2 lb) of fissile material, i.e., of about 2.6×10^{24} nuclei, is expressed in various units in Table 1.2.

Table 1.2 Energy Release in Complete Fission of 1 Kilogram

2×10^{13}	calories
8.4×10^{20}	ergs
6.2×10^{13}	foot-pounds
2.3×10^{7}	kilowatt-hours
7.9×10^{10}	Btu
20,000	tons TNT

It should be mentioned that not all of the energy liberated in fission is available to produce blast in a nuclear explosion. Due to the fact that some of the energy, in the form of thermal radiation and gamma rays, moves ahead of the shock wave, and for other reasons, only about 75 to 85 per cent of the fission energy contributes to the blast effect.

By comparing the available energy with that produced in the explosion of TNT, it has been estimated that the complete fission of 1 kg of uranium-235 would be as effective as 17 kilotons, i.e., 17 kt, of TNT, whereas 1 kg of plutonium-239 is equivalent to 19 kt of TNT. In other words, the energy yield per fission is equivalent to about 6.6×10^{-24} kt for uranium-235 and 7.3×10^{-24} kt TNT for plutonium-239. Although these numbers are known to be somewhat inexact, they are nevertheless used in calculations of energy yields, generally abbreviated to "yields," of nuclear weapons. Such yields are amost invariably expressed in terms of "kt," which is short for "kiloton TNT equivalent." A bomb with a yield of 20 kt is often referred to as a nominal atomic bomb, since this was roughly the energy release of the earliest (implosion) bombs.

1.2 The Fission Chain Reaction

Conditions for Chain Reaction

The condition for the maintenance of a fission chain reaction is, in essence, that for every fission caused by a neutron there should be produced another neutron capable of causing fission. Since the average number of neutrons produced in an act of fission is greater than two (Table 1.1), it would appear that a chain reaction in uranium-235 or plutonium-239 is inevitable. But this is not so, because not all the fission neutrons are available to carry on the chain, an appreciable proportion being lost in various ways. In a nuclear fission weapon, an important source of loss is leakage or escape of neutrons from the reacting system, so that many neutrons escape before being captured by a fissile nucleus. Some neutrons are also lost by parasitic capture, i.e., by capture in nonfission reactions of various kinds, either by the fissile material itself or by other nuclei.

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The fraction of neutrons escaping from a system in which fission is taking place can be decreased by increasing the size (or mass). Since neutrons are produced, by fission, throughout the whole volume, whereas escape takes place only from the exterior surface, it is evident that the escape probability will decrease as the volume-to-area ratio of the system is increased; this is achieved, for a given geometry, by increasing the dimensions.

Critical Size

In a very small mass of fissile material a self-sustaining chain reaction will not be possible because of the large proportion of neutrons that escape. But as the size is increased, the fraction of fission neutrons lost will decrease and ultimately a point is reached when for every neutron captured in a fission reaction another one will become available to carry on the fission chain. The system is then said to be critical, and a self-sustaining chain reaction is just possible. If a system is smaller than the critical size (or mass) it is referred to as subcritical, and if larger, it is called supercritical. In the latter case there are more neutrons available for fission at the end of each generation than were used up to cause fission at the beginning of that generation. It will be seen below that the critical mass or size is dependent on the nature of the fissile material, its shape, and several other factors.

Convergent, Stationary, and Divergent Chains

If ν is the average number of neutrons produced in each act of fission, on the average, and $\mathscr{l}$ is the average number lost, by escape and in other ways, e.g., by nonfission capture, then $\nu - \mathscr{l}$ is the number available to cause further fission; let this be represented by k, i.e.,

$$k = \nu - \mathscr{l} .$$

Thus, for every neutron causing fission in one generation, k neutrons will be available to cause fission in the next generation. Hence, in accordance with the preceding paragraph, k will be less than unity in a subcritical system; in a critical system k = 1; and in a supercritical system k will be greater than unity.

Suppose S neutrons are introduced into a fissile material and cause this number of fissions; then kS neutrons will be available for the next generation, k^2S for the next, and so on; at the end of n generations, the number of neutrons which can cause fission will be k^nS. Since, for a subcritical system, $k < 1$, it is evident that as n, the number of generations, increases, k^nS will approach zero. In other words, the number of neutrons will gradually decrease from one generation to the next; there is consequently a convergent or decaying fission chain which gradually dies out. For a system of critical size, k = 1, and then k^nS is always equal to S. The number of neutrons then remains constant from generation to generation. This is referred to as a stationary chain. Finally, if $k > 1$, as is the case for a supercritical system, k^nS increases steadily. The fission chain is then said to be a divergent or branching chain.

Prompt and Delayed Critical

In the foregoing discussion no distinction has been made between the prompt and delayed fission neutrons. As stated earlier, however, only the prompt neutrons are significant in fission weapons, and the critical size or mass is determined by the availability of the prompt neutrons, without regard to those which are delayed. This situation is often described as prompt critical. When both prompt and delayed neutrons are required to maintain the stationary chain, as in a nuclear reactor, the term delayed critical is sometimes used. Since more than 99 per cent of fission neutrons are prompt, the neglect of the delayed neutrons has little effect on the value of ν; hence, the data in Table 1.1 may still be used in essentially all calculations.

Factors Affecting Critical Mass

The critical size (or mass) is by no means a definite quantity, even for a given fissile material of specified composition. For one thing, the shape of the system has an influence on criticality, because the volume-to-area ratio varies with the geometry. The optimum condition is obtained with a sphere, for this has the largest ratio of volume to area, so that the probability of escape of neutrons is smaller than for any other shape. Thus, the critical mass of a sphere is less than that of any other geometrical form of the same material. As far as the material is concerned, it is evident that the presence of impurities will increase the critical mass of the fissile substance. Apart from the fact that the impurity may cause a loss of neutrons by parasitic capture, it adds area to the system, which increases the probability of neutron escape, without the compensating production of neutrons by fission.

It will be apparent, too, that the larger the value of ν, the smaller will be the critical size, under the same general conditions. If more neutrons are formed per fission, it will be possible to tolerate a somewhat larger loss and yet attain criticality. Hence, the critical size of plutonium-239 is less than that of uranium-235; since the densities are not very different, this is also true for the critical masses (see Table 1.3, below).

A factor which can partially compensate for a lower ν value is a smaller proportion of nonfission captures by the fissile material, since this will tend to increase the number of neutrons available for propagating the chain reaction. Although ν for uranium-233 is appreciably less than for plutonium-239, the critical masses, under equivalent conditions, do not appear to differ greatly. This is because nonfission capture in uranium-233 is relatively less than in plutonium-239.

The critical size is also dependent upon the mean free path of neutrons, i.e., the average crow-flight distance a neutron will travel before interacting with a nucleus, in a given material. If the mean free path is long, the probability that a neutron will escape from the system is also large. Consequently, under comparable conditions, the critical size will be greater than for a fissile material in which the neutrons have a shorter mean free path.

For a specified shape and composition, the size of a critical system can be decreased by surrounding it with a material which scatters neutrons back into the fissile core. By reducing the number of neutrons that escape, a smaller size (or mass) can become critical. Such a scattering material, on account of its function, is referred to, in general, as a reflector. In nuclear weapons it is called a tamper, because, in addition to decreasing the loss of neutrons by escape, it delays expansion of the exploding mass and permits a higher yield from the system undergoing fission, as will be seen later.

As is to be expected, increasing the thickness of the tamper decreases the escape of neutrons and thus makes possible a smaller critical mass of the fissile (or core) material. However, it has been shown by theoretical calculations, and verified experimentally, that when the tamper thickness reaches a certain value there is little more to be gained by a further increase of thickness (Fig. 1.2). Thus, when the thickness is about two to three neutron mean free paths in the given tamper material, its effectiveness in reducing neutron losses is within 10 per cent or so of an infinitely thick tamper.

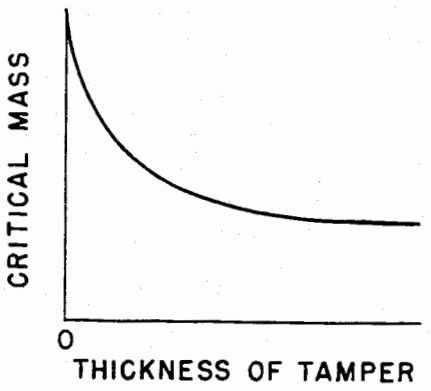


Fig. 1.2

Under precisely specified conditions, and for a given fissile (core) material, there is a definite mass that will be just critical. This is called a "crit." The critical masses of spheres of uranium-235 (94 per cent purity) and of plutonium-239 (97 per cent purity) are given in Table 1.3. In the first column are the values for a bare (untamped) sphere, whereas the values in the second column are for a thick (infinite) tamper of natural uranium metal. The effect of the tamper in reducing the critical mass of the core is very striking.

Table 1.3 Critical Masses of Spheres

Fissile Material	Bare	Tamped
Uranium-235	52 kg	17.2 kg
Plutonium-239	16 kg	5.8 kg

It may be noted that there is still another factor which affects the critical size: it is the speed (or energy) of the neutrons causing fission. The rate of the fission process is determined by the fission cross section, as will be seen later, and this varies with the neutron energy. However, as far as nuclear fission weapons are concerned, it may be tacitly assumed that only fast

neutrons, mainly with energies in the range from 0.5 to 2 Mev, are involved. Because of the relatively long slowing-down time, fission by slow neutrons would be less effective in an explosion.

1.3 Attainment of Criticality

Assembly Method (Gun-Type Weapons)

As long as a mass of fissile material is less than the critical value, i.e., it is subcritical for the existing conditions, there is no danger of a chain reaction occurring. But, if energy is to be released, e.g., in an explosion, the system must become critical and, in fact, highly supercritical, as will be seen shortly. There are two general ways, utilized in weapons, for rapidly converting a subcritical system of fissile material into one that is supercritical.

The first may be referred to as the method of assembly. Two portions of subcritical size are brought together very rapidly, so that the combined mass is supercritical. If a burst of neutrons is then introduced, a divergent fission chain will be initiated and there will be a rapid release of energy within a very short time. This is the principle used in weapons of the gun type: one subcritical portion of fissile material is shot into another subcritical portion, the combination exceeding the critical mass.

Compression Method (Implosion Weapons)

The second method of attaining criticality (or supercriticality) is based on compression of the subcritical fissile material. An approximate quantitative treatment of the relationship between the compression ratio and critical mass may be derived as follows. In accordance with the definition given above, the mean free path of a neutron is the average (crow-flight) distance a neutron travels before it interacts with a nucleus. The proportion of neutrons avoiding interaction, and which can consequently escape from the system, will evidently depend on the ratio of the dimensions, e.g., the radius of a sphere, to the mean free path. It is to be expected, therefore, that for a given fissile (core) material, under specified conditions, the critical radius will be approximately proportional to the neutron mean free path; thus, if R_c is the critical radius and λ_c is the mean free path in the core,

$$R_c \propto \lambda_c. \qquad (1.3)$$

The mean free path of a neutron is obviously inversely related to the probability of its interaction; the greater the probability of interaction, the smaller the distance the neutron will travel before it interacts with a nucleus. The probability of interaction is proportional to the number of fissile nuclei per unit volume, and hence to the density; so that, if ρ_c is the density of the core material,

$$\lambda_c \propto \frac{1}{\rho_c} . \tag{1.4}$$

The density of the material is dependent on the compression; thus, if C is the compression ratio, i.e., the volume before compression to that after,

$$C \propto \rho_c . \tag{1.5}$$

Combination of equations (1.3), (1.4), and (1.5) then leads to the result

$$R_c \propto \frac{1}{C} . \tag{1.6}$$

The critical mass M_c is related to the critical radius and the density of the material by

$$M_c = \frac{4}{3}\pi R_c^3 \rho_c , \tag{1.7}$$

and upon substituting equation (1.6) for R_c and equation (1.5) for ρ_c, it is seen that

$$M_c \propto \frac{1}{C^2} . \tag{1.8}$$

The critical mass of a given fissile material is thus inversely proportional to the square of the compression ratio. By increasing the compression the critical mass is consequently decreased.

It follows, therefore, that if a subcritical mass of fissile material is compressed it may become supercritical. [redacted] In other words, it will be highly supercritical, and the introduction of neutrons will cause a rapidly divergent fission chain to develop.

If the mass of fissile (core) material is tamped, then the result in equation (1.8) is true only if both the tamper and the core are compressed to the same extent. Actually, uniform compression is not attained throughout; it is greater near the center of the bomb, i.e., in the core, than further out, e.g., in the tamper. Even within the core itself there is a compression gradient. In general, therefore, the relationship between the critical mass and the average compression ratios of the core (C_c) and of the tamper (C_t) may be represented by

$$M_c \propto \frac{1}{C_c^{1.2}} \cdot \frac{1}{C_t^{0.8}} , \tag{1.9}$$

so that when C_c and C_t are identical, this reduces to equation (1.8). For most cases of interest in the weapons field, a good approximation is

$$M_c \propto \frac{1}{C_c^{1.7}} \quad , \tag{1.10}$$

since the conditions are such that the tamper is compressed to a smaller extent than is the core.

The use of compression to attain supercriticality is employed in weapons of the implosion type; the reason for this name will be seen later. Not only does increased compression result in a decrease in critical mass, it is also accompanied by an increase in efficiency of the energy release, as will be seen in Section 2.1. Consequently, the attainment of higher and higher compressions is one of the important objectives of weapon development.

1.4 Neutron Multiplication

Rate of Fission Reaction

No matter how it originates, an explosion involves the very rapid liberation of a large amount of energy. If the energy is to be produced by fission, then the necessary condition is a very high neutron density, since the rate of fission, and, hence, the rate of energy release, is proportional to the number of neutrons per unit volume. It is of interest, therefore, to investigate the circumstances which lead to a high neutron density.

It was seen earlier that the number of neutrons available to cause fission, for every neutron captured in a fission process, in each generation is equal to k, i.e., to $\nu - \ell$, where ν is the average number of neutrons produced per fission and ℓ is the average number lost by escape and nonfission capture. This means that for every n neutrons present at the beginning of a generation, there will be nk present at the end, so that the gain of neutrons is n(k - 1) per generation. The rate of gain, dn/dt, may then be obtained, roughly, upon dividing the actual gain by the average time, τ, between successive fission generations; hence,

$$\frac{dn}{dt} = \frac{n(k-1)}{\tau}. \tag{1.11}$$

This result will be strictly correct only if the delayed neutrons play no significant part in maintaining the fission chain. As seen above, this condition is applicable to nuclear fission weapons.

The quantity k - 1, which is the excess number of available neutrons per fission, may be

represented by f*, i.e.,

$$f = k - 1 = \nu - \ell - 1 \tag{1.12}$$

and then

$$\frac{dn}{dt} = n\frac{f}{\tau}. \tag{1.13}$$

It is customary to use the symbol α for the quantity f/τ, i.e.,

$$\alpha \equiv f/\tau, \tag{1.14}$$

so that

$$\frac{dn}{dt} = \alpha n. \tag{1.15}$$

Thus, the rate of increase in the neutron population (or neutron density) is dependent upon α, and this should be made as large as possible.

It is seen from equation (1.15) that α is a rate constant or specific rate. In nuclear weapons work it is frequently called the multiplication rate or merely "alpha." Its value depends on the conditions existing at any time. According to equation (1.15), if α is negative, i.e., $\alpha < 0$, then dn/dt will be negative and the number of neutrons will decrease with time. Since α is equal to f/τ, and τ is always positive, this condition will arise when f is negative. From equation (1.12) this means that k - 1 is negative, or $k < 1$, i.e., when the system is subcritical. Hence, is agreement with previous conclusions, the fission chain in a subcritical system will eventually die out because of the steady decrease in the neutron population. If α is zero, i.e., $f = 0$ and $k = 1$, the system is critical, and, by equation (1.15), the neutron density will remain constant. Finally, if α is positive, so that $f > 0$ and $k > 1$, the system is supercritical and there will be a steady increase in the neutron population.

If equation (1.15) is written in the form

$$\frac{dn}{n} = \alpha dt,$$

*In LASL reports, the symbol f has a significance which is somewhat different from that given here. It is a purely nuclear property of the fissile material, for neutrons of a specified energy, giving the excess neutrons per collision in a system from which neutrons do not escape. Thus,

$$f = \frac{\sigma_f}{\sigma_t}\left(\nu - 1 - \frac{\sigma_c}{\sigma_f}\right),$$

where σ_f, σ_c, and σ_t are the fission, nonfission capture, and total cross sections, respectively. The accepted values of f are 0.35 for uranium-235 (oralloy) and 0.69 for plutonium.

and α is supposed to remain constant, this expression can be readily integrated between the time limits of zero, when the number of neutrons present is n_o, and t, when the number has increased to n. The result is

$$n = n_o e^{\alpha t}, \tag{1.16}$$

where e, as usual, is the base of natural logarithms. Thus, if α is known, the neutron population at any time t can be calculated, relative to the value at an arbitrary zero time. It can be seen from equation (1.16) that $1/\alpha$ is the time period during which the number of neutrons increases by a factor e; consequently, $1/\alpha$ is often referred to as the e-folding time, i.e., the time in which there is an e-fold increase in neutron population.

Conditions for Nuclear Explosion

In order to achieve a nuclear explosion there must be a very rapid release of a large amount of fission energy. The rate of the fission process is proportional to the neutron density and so the conditions for an explosion can be realized if both α and n in equation (1.16) are large. Since n depends upon α, the value of the latter is essentially the determining factor. In general, the magnitude of α largely determines the efficiency of a nuclear fission explosion. It is of interest, therefore, to consider how α may be made as large as possible.

By the definitions of equations (1.12) and (1.14),

$$\alpha \equiv \frac{\nu - \ell - 1}{\tau}, \tag{1.17}$$

so that to increase α, it is necessary that $\nu - \ell - 1$ should be large and τ small. The value of ν is a specific property of the fissile material and, for a given substance, cannot be altered. The relative neutron loss, ℓ , can be decreased by making the system highly supercritical, e.g., by assembly or compression, as already described, or by means of a tamper. However, once the fission chain has been started ℓ remains roughly constant, as long as the volume of the system does not change appreciably. If the volume increases, then the neutron loss increase and α decreases, correspondingly. The importance of this effect of volume change will be seen later.

The significant factor in the determination of α is, consequently, the generation time, τ. This is approximately equal to λ, the fission mean free path of the neutrons in the core material, divided by the speed, v, of the neutrons causing fission, i.e.,

$$\tau \approx \frac{\lambda}{v}, \tag{1.18}$$

so that the ratio λ/v should be made as small as possible. It should be noted that the fission mean free path in equation (1.18) is not the same as the mean free path for all interactions used earlier. The λ used here is the average distance a neutron travels before it is captured in a fission reaction.

The fission mean free path is equal to $1/N\sigma_f$, where N is the number of fissile nuclei per cm^3 and σ_f is the fission cross section.* Hence, from equation (1.18),

$$\tau \approx \frac{1}{N\sigma_f v}, \qquad (1.19)$$

so that the generation time is inversely related to the product $\sigma_f v$.

*For the present purpose, the cross section may be regarded as the effective area of a nucleus for a particular reaction (or reactions). It is usually expressed in barns, i.e., 10^{-24} cm^2 units.

It is evident, therefore, that in order to achieve a nuclear explosion, fission should be brought about by fast neutrons, as far as possible.

According to equation (1.19), the generation time for neutrons of given energy (or velocity) is inversely proportional to the number (N) of fissile nuclei per cm^3. It follows, therefore, that τ is inversely proportional to C_c, the core compression; thus,

$$\tau \propto \frac{1}{C_c} . \qquad (1.20)$$

Consequently, the generation time can be decreased, and the value of α increased, by compression of the core material.

In addition to the effect of compression on τ, it also causes a marked decrease in ℓ, as indicated above, so that f is increased appreciably. It follows, therefore, from equation (1.14 that compression of the core will greatly increase α because of the simultaneous increase in f and decrease in τ.

Further, leakage of neutrons must be kept as low as possible in the exploding system. Finally, increased compression is a highly favorable factor, since it reduces leakage and shortens the generation time. Compression also increases the efficiency of the explosion, as will be seen in the next chapter.

Thus for fast-neutron fission, α is about 10^8 sec^{-1} in a supercritical system and τ, the generation time, is roughly 10^{-8} sec (or about 1 shake). Experimental determinations (see Chapter 6) give values for α in very good agreement with this calculation. It is the common practice to express the results in reciprocal shakes, i.e., 10^8 sec^{-1} units, so that in the example given above $\alpha \approx 1$ $shake^{-1}$.

Explosion Time

It will be noted, incidentally, that $1/\alpha$, the e-folding time, is of the same order as τ, the generation time. Consequently, $1/\alpha$ is frequently identified with the generation time, and αt is then the number of generations which have elapsed during the time interval t. It is thus possible to write equation (1.16) in the approximate form

$$n \approx n_o e^g, \tag{1.21}$$

where g is the number of generations in which the neutron density increases from n_o to n. In other words, the neutron population increases roughly by a factor of e per generation, i.e., by a factor of 10 in every 2.3 generations.

Before a fissioning system can explode, i.e., before the material commences to move outward, a certain energy density must be attained.

The fission chain reaction then gradually dies out, because the increasing rate of neutron escape causes α to decrease and eventually to become negative.

Obviously, to obtain a high efficiency, the expansion of the core must be delayed as much as possible, and this is an important function which must be fulfilled by the tamper.

Spontaneous Fission

The fission processes discussed so far have been those involving the deliberate introduction of neutrons. These reactions can also be brought about by extraneous neutrons, such as those present in cosmic rays or resulting from the action of alpha particles, emitted by uranium or plutonium, on certain impurities. In addition, there is the possibility of completely spontaneous fission of certain nuclei, without the intervention of neutrons. It is important to point out, however, that such spontaneous fissions are, nevertheless, accompanied by neutron emission and the latter are capable of causing further fissions.

The spontaneous fission rates, expressed as the number of nuclei undergoing fission per hour per gram of material, of some isotopes of uranium and plutonium are given in Table 1.4. Since two to three neutrons are liberated per fission, the rate of neutron emission is obtained upon multiplication of the fission rates by the appropriate number. The spontaneous fission rates of uranium-233, uranium-235, uranium-238, and plutonium-239 are fairly small, but those

Table 1.4 Spontaneous Fission Rates

Isotope	Fission/hour/gram
Uranium-233	< 0.7
Uranium-234	<30
Uranium-235	1.3
Uranium-238	24
Plutonium-238	1.1×10^7
Plutonium-239	35
Plutonium-240	1.6×10^6

of plutonium-238 and -240 are considerable. The former of these two isotopes is of no significance in the production of weapons, but some plutonium-240 is almost invariably present in plutonium-239 and its high spontaneous fission rate is of serious consequence in connection with fission weapons.

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1.5 Production of Weapon Materials

Uranium-235

The two important fissile materials, namely, uranium-235 and plutonium-239, are both produced from natural uranium but by entirely different procedures. Ordinary uranium contains about 0.7 per cent of uranium-235 to 99.3 per cent of uranium-238, and a trace (0.006 per cent) of uranium-234. The uranium-235 is separated by diffusion (through porous barriers) of the vapor of uranium hexafluoride (UF_6), made from natural uranium. The hexafluoride of the lighter isotope diffuses more rapidly than does that of the heavier species, and by the use of several thousand diffusion stages an enrichment of 93.5 per cent, i.e., a material containing an isotopic proportion of 93.5 per cent of uranium-235, can be obtained. The highly enriched uranium hexafluoride is then converted into the tetrafluoride (UF_4) by heating with hydrogen or methane. The uranium tetrafluoride is reduced to metal by means of calcium plus some iodine to act as a "thermal booster." Reaction between iodine and part of the calcium starts at about 400°C; the heat generated raises the temperature sufficiently for rapid reduction of the tetrafluoride by calcium to take place

Plutonium-239

The element plutonium occurs in nature as virtually insignificant traces, at best. Consequently, the plutonium-239 used in weapons is obtained artifically by a series of nuclear reactions resulting from the exposure of uranium-238 to slow neutrons in a nuclear reactor or "pile." A nuclear reactor is a device in which a fission chain reaction is taking place in a controlled manner. If a material of low mass number, called a moderator, is present, in addition to fissile material, the fission neutrons will be slowed down, and such a system is, in a sense, a source of slow neutrons.

In a reactor, uranium-238 captures neutrons to form a higher isotope, uranium-239, with the emission of gamma radiation; thus

$$_{92}U^{238} + {}_{0}n^{1} \longrightarrow {}_{92}U^{239} + \gamma,$$

where the subscripts give the atomic numbers, i.e., number of protons, and the superscripts indicate the mass numbers, i.e., total number of neutrons and protons in each case. The uranium-239 is radioactive, with a half life of 23 min, emitting a beta particle. Representing the latter by $_{-1}\beta^{0}$, since it carries a negative charge and has essentially no mass, the radioactive decay process may be written as

$$_{92}U^{239} \longrightarrow {}_{-1}\beta^{0} + {}_{93}Np^{239},$$

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the product being an isotope of a new element, atomic number 93, called neptunium (Np), of mass number 239. Neptunium-239 is also radioactive, half life 2.3 days; it emits a beta particle according to the reaction

$$_{93}Np^{239} \longrightarrow {}_{-1}\beta^{0} + {}_{94}Pu^{239},$$

so that the product, atomic number 94, mass number 239, is plutonium-239. This is an alpha emitter with a fairly long half life--about 24,000 years--and hence it is relatively stable.

It may be mentioned that the decay product of plutonium-239 is the fissile uranium-235, its half life being about 9×10^{8} years. Hence, as far as fission is concerned, plutonium will undergo only relatively minor changes over a period of several hundred years. The same is true, of course, to an even greater extent, for uranium-235.

As the plutonium-239 accumulates in a reactor, it also begins to capture neutrons, the rate of capture being proportional to the neutron density and to the concentration of plutonium-239 nuclei. The process is

$$_{93}Pu^{239} + {}_{0}n^{1} \longrightarrow {}_{94}Pu^{240} + \gamma$$

with plutonium-240, an alpha emitter of half life about 6500 years, as the product. The two isotopes of plutonium cannot be separated from each other in the chemical process used for the extraction of plutonium from the fission products and the unchanged uranium discharged from a production reactor. Hence, plutonium-239 is always associated with a certain proportion of plutonium-240, the amount increasing, up to a limiting value, with the exposure time of the material in the reactor, and also with the neutron density.

The amount of plutonium-240 present in the uranium fuel elements, as they are called, increases, up to a limiting value of about 35 per cent, with the time spent in the reactor and with the reactor power. Consequently, the quality of plutonium, as regards its plutonium-240 content, is frequently described in terms of megawatt-days of exposure in the reactor per ton of uranium fuel, i.e., in MWD/T units. Actually, the unit is not too precise because the reactor power is not uniform throughout its volume, so that the plutonium-240 content corresponding to a given average MWD/T value depends on the location of the fuel element in the reactor. However, because many fuel elements ("slugs") are processed simultaneously, this tends to average out sufficiently well for practical purposes.

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At the present time essentially all the plutonium in the United States is made at Hanford, Wash., in reactors employing natural uranium, in the metallic form, with graphite as the moderator for slowing down the neutrons. The uranium-235 present maintains the fission chain, while the uranium-238 captures some of the neutrons. This leads, ultimately, to the formation of plutonium-239, as seen above. In the new production plant being built at Savannah River, S.C., natural uranium will be the fuel, as at Hanford, but the moderator will be heavy water, i.e., water highly enriched in the heavier isotope, deuterium.

Code Names

There are a number of code names and symbols frequently employed in connection with nuclear weapons work. Uranium metal enriched in the uranium-235 isotope, originating in Oak Ridge, is often called oralloy, an abbreviation of "Oak Ridge alloy." It is represented by the symbol Oy, followed by a number in parentheses indicating the percentage enrichment; thus Oy(93.5) indicates a material containing 93.5 per cent of uranium-235 and 6.5 per cent of uranium-238 and other isotopes. Until recently, this was the only form of enriched material in general use and it is this composition which is frequently referred to as oralloy or Oy, without qualification. However, some applications of a less enriched product, Oy(37.5), are now being made.

The corresponding code name tuballoy, symbol Tu, is used for uranium metal, in the normal isotopic proportions, i.e., 99.3 per cent uranium-238. It is based on the designation Tube Alloys Limited applied to the British wartime atomic energy project. The metal obtained from the depleted uranium residues of the gaseous diffusion plants, containing more than 99.3 per cent of uranium-238, is sometimes called "Q" metal.

The names mentioned above are generally used for specific materials. A (declassified) code system of another kind is frequently employed to represent particular isotopes. The last numerals of the atomic number and of the mass number are combined to give a two-digit symbol that is characteristic of the particular species. Thus, uranium-235, mass number 92, is referred to as "25"; uranium-238 is "28"; and plutonium-239, atomic number 94, is "49".

*Up to 1000 MWD/T, at least, the percentage of plutonium-240 is roughly proportional to the exposure.

Production of Neutrons

In an atomic weapon, the chain reaction is initiated by the introduction of neutrons into the highly supercritical system. Consequently, the methods for producing neutrons may be briefly reviewed. Two main procedures will be considered here, others will be mentioned in Section 1.6.

One of the simplest methods for obtaining neutrons is by the action of alpha particles of sufficient energy on certain light elements, notably beryllium. The reaction may be represented by

$$_2He^4 + {}_4Be^9 \longrightarrow {}_6C^{12} + {}_0n^1,$$

recalling that the alpha particle is identical with a helium nucleus. For laboratory purposes, radium is a very convenient source of alpha particles, but for several reasons it is not practical for use in nuclear weapons. The alpha-particle source employed is the radioelement polonium-210. This has the advantage of being relatively simple to make and, unlike radium, neither plutonium itself nor its radioactive decay products emit gamma radiation. Polonium-210 is produced by exposure of bismuth to neutrons in a nuclear reactor, when the reaction

$$_{83}Bi^{209} + {}_0n^1 \longrightarrow {}_{83}Bi^{210} + \gamma$$

occurs. The bismuth-210 is a beta-emitter, with a half life of 5 days, and so it soon decays to form polonium-210; thus,

$$_{83}Bi^{210} \longrightarrow {}_{-1}\beta^0 + {}_{84}Po^{210}.$$

The use of polonium-210 has, however, three drawbacks. Its half life is only 138.4 days, so that the neutron source has a short stockpile life and requires frequent replacement. In addition, the polonium constitutes a health hazard and special precautions must be taken in fabrication. Finally, its production requires neutrons which could otherwise be used for making plutonium. There is consequently considerable interest in the development of neutron sources which do not involve polonium.

DOE b(3)

1.6 Thermonuclear Reactions

Limitations of Energy Release

It should be apparent from the earlier discussion that the energy release of a nuclear fission weapon is limited by the mass of fissile material which can be included in it and yet retain a subcritical system. It should be remembered, of course, that the critical mass depends on the geometry of the system. Consequently, if desired, a large mass of fissile material can be made subcritical by fabrication into a form in which it has a large exposed area, e.g., a spherical shell.

DOE b(3)

Fusion Reactions

Nuclear reactions of the fusion type were first attained in the laboratory by using charged particles, e.g., protons (hydrogen nuclei), deuterons (deuterium nuclei), or tritons (tritium nuclei), which were accelerated in a cyclotron, Van de Graaff generator, or similar device. In this manner, the nuclear particles acquire sufficient energy to permit them to react with other light nuclei. Since this energy is merely kinetic energy, it is not different from that which a nucleus would acquire as a result of raising its temperature. Thus, assuming a Maxwell-Boltzmann distribution of energy among the nuclei, it is found that the mean kinetic energy corresponding to a temperature of T^{o} Kelvin is $8.6 \times 10^{-11} T$ Mev. Consequently, it is to be expected, and has been confirmed by experiment, that nuclear reactions can be brought about by the use of high temperatures. Such processes are referred to as thermonuclear reactions.

The thermonuclear reactions which have been achieved so far involve only the heavier isotopes of hydrogen, i.e., deuterium and tritium.* This is because the necessary kinetic energies are lower, and, hence, so also are the requisite temperatures, than for other nuclear processes.

As a first approximation, the minimum interaction energy may be regarded as that required to overcome the electrostatic repulsion forces operating between the interacting nuclei. If Z and Z' are the respective positive charges, i.e., atomic numbers, and r is the distance

*The descriptions given here refer only to thermonuclear processes achieved by man; these and other such reactions take place in various heavenly bodies and constitute their energy sources.

between the nuclei, the coulombic repulsion energy is $ZZ' e^2/r$, where e is the value of the electronic charge. This energy will be least for reactions between hydrogen nuclei, since Z and Z' are then both unity; the repulsion energy which must be overcome is consequently e^2/r.

If electrostatic repulsion were the determining factor, the energy required for the above reactions would be roughly 0.1 Mev; this would correspond to the extremely high temperature of about 10^9 °K. However, for various reasons, which are explicable in terms of quantum mechanics, it has been found that the reactions involving deuterium and tritium will take place at an appreciable rate at energies of the order of 1 to 10 kev, i.e., 10^{-3} to 10^{-2} Mev.

DOE (3)

Three thermonuclear reactions are of particular importance. These are represented below, together with the amount of energy released as calculated from the masses of the nuclei involved:

$$_1D^2 + {}_1D^2 \longrightarrow {}_1H^1 + {}_1T^3 + 4.0 \text{ Mev}$$

$$_1D^2 + {}_1D^2 \longrightarrow {}_0n^1 + {}_2He^3 + 3.3 \text{ Mev}$$

$$_1D^2 + {}_1T^3 \longrightarrow {}_0n^1 + {}_2H^4 + 17.6 \text{ Mev}$$

The D-D and D-T reactions have possible applications in two different directions to be described shortly.

Thermonuclear Energy Release

Since the energy liberated in these reactions is several Mev in each case, whereas they can be initiated, at least, by energies of from 1 to 10 kev, it is apparent that a kind of thermonuclear chain is possible. Thus, if the energy liberated in the reaction between a quantity (or volume) of deuterium nuclei can be used to raise the temperature of other such nuclei, then further D-D reactions will result, and a self-sustaining thermonuclear propagation will be possible. As in the case of the fission chain, this will be accompanied by the continuous release of energy. Whereas in the fission reaction the chain is maintained by neutrons, the thermonuclear propagation is maintained by thermal energy.

*It has become the practice in thermonuclear work to express the temperature in terms of the equivalent kinetic energy. Thus, reactions involving deuterium and tritium are said to take place at "temperatures of 1 to 10 kev."

It may be remarked that in many respects thermonuclear propagation (or burning) is analogous to the process which takes place in an internal combustion engine. The spark initiates the reaction between a quantity of oxygen and gasoline; the energy generated then raises the temperature of adjacent material to such an extent that reaction can occur, and so on.

Thermonuclear Neutron Production

It will be observed that one of the D-D reactions and the D-T reaction, referred to above, yield neutrons as a product. In the latter case, the energy of the neutrons is about 14 Mev, as may be readily calculated on the basis of conservation of momentum between the neutron and the helium nucleus formed in the process. Neutrons produced by these thermonuclear processes have been used to initiate the fission chain or to introduce a burst of neutrons at a later stage in order to maintain and enhance the progress of the fission reaction.

It should be noted that the D-D reaction which leads to the formation of H and T will be followed by interaction between the tritium and any unchanged deuterium nuclei that may still be present. This D-T reaction will, of course, result in the production of additional neutrons.

Thermonuclear Weapons

One of the reasons for the interest in thermonuclear weapons has been indicated earlier. The energy release of a fission weapon is limited by safety considerations which make it necessary to maintain the fissile material, before detonation, in a subcritical state. Deuterium and tritium, on the other hand, can be safely held in large volumes, and the amounts that could be included in a weapon would be determined only by practical considerations. Consequently, the energy yield of a weapon utilizing the deuterium and tritium reactions would be limited only by the quantity of material that could be used. Thus, weapons of extremely high yields are feasible at a considerably lower cost than is possible for equivalent fission weapons.

Tritium is made in nuclear reactors and its production involves the capture of a neutron by a lithium nucleus, as will be explained shortly. The same neutron could be used to produce plutonium, and so each tritium atom formed represents the loss of an atom of plutonium. In a reactor using natural uranium as fuel there will inevitably be some plutonium production, and so, even if it were desirable, the available neutrons could not be used exclusively for tritium production. Consequently, this isotope will be expensive and not too common. There is a possibility that lithium could be used, in place of cadmium, as a central absorber to make the neutron flux (and heat liberation) in a nuclear reactor more uniform. In this event, tritium would be produced by means of neutrons which are otherwise wasted.

A further matter of significance may be mentioned: tritium is radioactive, and its half life is only about 12.5 years. Hence, in addition to being somewhat of a health hazard, it decreases in amount at an appreciable rate. The beta-decay product is helium-3, and this can react with

deuterium to yield a fairly large amount of energy, i.e.,

$$_1D^2 + {}_2He^3 \longrightarrow {}_1H^1 + {}_2He^4 + 17.6 \text{ Mev},$$

but the higher charge of the helium nucleus makes this reaction less probable than the D-T reaction. However, when neutrons are available, e.g., from a D-D or D-T reaction, the tritium may be regenerated by the reaction

$$_2He^3 + {}_on^1 \longrightarrow {}_1T^3 + {}_1H^1.$$

In a nuclear reactor, one neutron can be made to yield one plutonium atom or one tritium atom. But whereas fission of a plutonium atom liberates about 200 Mev, a thermonuclear reaction with tritium rêleases only 18 Mev. It would thus seem, at first sight, that use of tritium in a weapon would be a highly uneconomic procedure. The justification lies, however, in the fact that a relatively small amount of tritium may be made, in various ways, to help initiate a D-D reation in a large quantity of the much less expensive and more readily available deuterium.

Production of Deuterium and Tritium

Deuterium oxide (heavy water) is present to the extent of about 1 part in 6500, i.e., 0.015 per cent, in ordinary water. In spite of this very small proportion, enrichment of water in deuterium is not too difficult, and heavy water of 99 per cent purity is now produced on the industrial scale. Large quantities are required to supply the need for a moderator in the Savannah River, S.C., plant for plutonium and tritium production.

Three main processes have been used to achieve a partial separation of the hydrogen isotopes in water: these are (a) isotopic (chemical) exchange, (b) distillation, and (c) electrolysis. In the isotopic exchange process, hydrogen gas or a gaseous compound of hydrogen is made to react with liquid water. As a result of the somewhat different reactivities of the two isotopes, there is a partial separation between the liquid and gaseous phases. The large-scale production process now operated by AEC contractors, utilizes the reaction between hydrogen sulfide gas and water. The exchange reaction results in a relatively higher proportion of deuterium in the liquid phase than in the gas. By utilizing a countercurrent flow of gas and liquid in several stages, considerable enrichment in deuterium can be achieved in the liquid.

The distillation method for separating the isotopes of hydrogen depends on the fact that heavy water has a slighly higher boiling point, i.e., lower vapor pressure, than light water. Consequently, a partial separation can be achieved by fractional distillation, preferably under reduced pressure.

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When a slightly acid or alkaline solution in water is electrolyzed, the hydrogen gas liberated at the cathode contains relatively more of the lighter isotope than does the water. By repeated electrolysis in stages, heavy water of a high degree of enrichment can be obtained.

Each of the three foregoing procedures has certain advantages under suitable conditions. Hence, for the production of heavy water in quantity, ordinary water is first partially enriched by the isotopic exchange process. The deuterium is further concentrated by fractional distillation under vacuum, and then it is finally brought up to about 99 per cent enrichment by electrolysis. Deuterium itself can be released from heavy water by any of the familiar chemical methods used to prepare hydrogen gas. It can then be converted into any compound that may be required, or it may be liquefied by cooling under pressure, in the usual manner, to obtain liquid deuterium.

Tritium is produced by exposure of lithium to slow neutrons in a nuclear reactor; the less abundant lithium-6 isotope then undergoes the reaction

$$ {}_3Li^6 + {}_0n^1 \longrightarrow {}_2He^4 + {}_1T^3 $$

with the formation of tritium. This isotope can be converted into compounds or liquefied, just like other forms of hydrogen. It is expected that larger quantities of tritium will become available when the reactors at the Savannah River plant commence operation.

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Chapter 2

Efficiency of Fission Weapons

2.1 Determination of Efficiency

Definition of Efficiency

The efficiency (ϕ) of any weapon may be defined as the ratio of the energy actually developed when it explodes, i.e., the energy yield, to the total energy available, i.e.,

$$\phi = \frac{\text{energy yield}}{\text{energy available}} \tag{2.1}$$

In other words, it is the fraction of the energy available which is actually released in the explosion. In the case of a fission weapon this is equal to the ratio of the number of nuclei which actually undergo fission to the total number of fissile nuclei present.

In designing a fission weapon it is essential to be able to estimate its yield from theoretical considerations. But the calculation of the efficiency is very complicated, involving a detailed hydrodynamic treatment of the core material and tamper during the main period of energy release, i.e., in the interval between about the 50th and 55th generations after initiation of the fission chain. With the availability of high-speed electronic computers, such as the IBM 701 and the MANIAC, progress is now being made in the rapid calculation of the efficiency of any proposed fission weapon. However, the procedures are tedious and not necessarily complete, so that other, partially empirical, methods for determining efficiencies are still in general use.

Detailed Calculation Procedure

The following description is intended as a brief outline of the detailed method for calculating weapon yields (or efficiencies); its purpose is merely to give a general indication of the procedure used. The bomb assembly is divided, somewhat arbitrarily, into a finite number of concentric shells, and the time behavior of each shell, or "mass point," is determined by numerical calculations using equations describing the processes of neutron production, material acceleration, and heat flow. The initial time for purposes of these calculations, at which significant physical effects may be assumed to begin, is taken as that after the 50th generation. Up to this time the mass points are essentially stationary, and very little energy has been liberated. The subsequent changes with time, as the system expands, are treated by calculating the neutron density, position, and physical properties of the mass points at time $t + \Delta t$ in terms of those existing at time t. For convenience, different time intervals Δt may be taken for different purposes.

Starting with the initial radii, masses, and nature of the fissile material for the several mass points, the values of α and of the neutron distribution at the zero time can be determined

by some form of neutron transport theory. Then, making use of this alpha and the familiar equation (1.16), for the time rate of increase of neutron population, the neutron distribution after the interval Δt can be evaluated.

The next step is to determine the acceleration of the mass points by hydrodynamic calculations; this gives the velocity at Δt, from which the new radii of the mass points can be obtained. Finally, the temperature distribution is calculated from the heat flow equation, taking into account the energy produced by fission, the work done by the mass points in their outward motion, and the transfer of energy by radiation.

These calculations complete one cycle, since the new neutron densities, radii, and temperatures of the mass points are now known. From the temperatures, the new physical properties are determined. The whole procedure, starting with alpha and the neutron distribution, is repeated over and over until the bomb has completely exploded and the rate of energy release by fission has fallen almost to zero. Upon summing the number of fissions which have taken place, the total energy yield can be obtained. This includes the energy released by fission after the system has expanded and become subcritical. Although chain propagation is no longer possible, interaction of the many neutrons and fissile nuclei still present will result in a considerable energy production; this may amount to some 30 per cent of the total yield.

The Bethe-Feynman Formula

The formula for the efficiency of a nuclear explosion derived by Bethe and Feynman is admittedly approximate since it involves a number of simplifying assumptions. It is based largely on the following arguments. As a result of the energy liberated in fission, very large pressures are developed in the core, and the core-tamper interface consequently receives a large outward acceleration. This causes highly compressed tamper material to pile up just ahead of the expanding interface, in an effect referred to as the "snowplow" phenomenon, because of its similarity to the piling up of snow in front of a snowplow. The inertia of the compressed tamper will delay expansion of the core, so that a considerable pressure gradient will build up from the center of the core to its outer surface.

Further, as a result of the delayed expansion, it may be supposed that the volume of compressed core remains essentially constant during the first 50 or so generations following initiation of the fission chain. After this interval, almost the whole of the bomb energy is released within an extremely short period, during which time the core expands rapidly until it becomes subcritical. Although there is an appreciable energy release in this state, as seen above, the liberation of energy may be regarded as over when the dimensions are just critical. It will be assumed, in the subsequent treatment, that during the very short period while the energy is being released, none escapes from the system. It may be remarked that most of the

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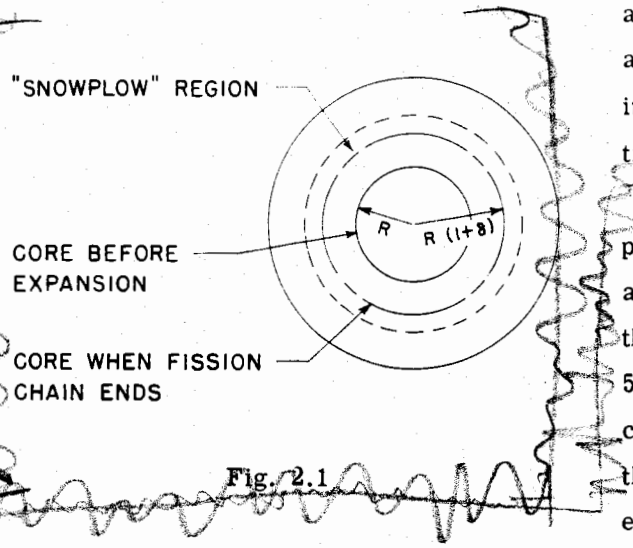


Fig. 2.1

approximations and assumptions involved are applicable when the efficiency is small, and it is for this condition that the Bethe-Feynman treatment is justifiable.

Let R be the radius of the core at the point of maximum supercriticality; then, in accordance with the postulate made above, this will remain unchanged until about the 50th generation after initiation of the fission chain. Subsequently, the energy content of the system becomes so large that mechanical effects begin and the core starts to expand. Suppose that when the core has expanded by a fraction δ, so that the radius is $R(1 + \delta)$, the system is just critical (Fig. 2.1). Beyond this point the core material will be subcritical; the fission chain will end and there will be, according to an earlier assumption, essentially no further release of energy.

Consider a thin shell of material in the core, of volume dV and thickness dr; the cross-sectional area of the shell is then dV/dr. If dP is the pressure difference on the two sides of this shell, caused by the fission energy liberated, the net outward force, F, to which the shell is subjected, i.e., pressure x area, is then

$$F = dP \frac{dV}{dr} = \frac{dP}{dr} dV \ , \qquad (2.2)$$

where dP/dr is the pressure gradient in the given shell. As a reasonable approximation, it may be supposed that the pressure gradient is constant throughout the core, so that it is possible to write

$$\frac{dP}{dr} \approx \frac{P}{R} \ , \qquad (2.3)$$

where P is the total difference in pressure from the center of the core to the outer surface. Hence, from equations (2.2) and (2.3),

$$F \approx \frac{P}{R} dV \ . \qquad (2.4)$$

The time required for the core to expand from radius R to $R(1 -$ [illegible] distance of $R\delta$, is about five generations. However, as a rough approximation this [illegible] taken as $1/\alpha$, where α is the multiplication rate when fission is initiated, as described in 1.4.

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Hence, the mean outward acceleration of the core material, and of the shell dV, may be expressed as $R\delta\alpha^2$. The mass of the shell is $\rho_c dV$, where ρ_c is the core density, and, hence, by Newton's second law of motion, i.e., force = mass x acceleration, the force acting on the shell is given by

$$F \approx R\delta\alpha^2 \times \rho_c dV \ .$$

Upon comparing this result with equation (2.4), it is seen that

$$P \approx \rho_c R^2 \alpha^2 \delta \ . \tag{2.5}$$

At the existing temperatures the core material will be in the gaseous state, and if, as postulated, the loss of energy from the system during the initial expansion is negligible, it may be considered as a gas undergoing an adiabatic process. The total energy of such a gas, which may be regarded as equal to the energy of the core, is then

$$E = \frac{PV}{\gamma - 1} \ , \tag{2.6}$$

where γ is the ratio of the specific heats of the gas. Using equation (2.5) for P and writing M/ρ_c for the volume of the core, M being the mass, equation (2.6) becomes

$$E \approx \frac{MR^2\alpha^2\delta}{\gamma - 1} \ . \tag{2.7}$$

If ϵ is the energy released in the complete fission of unit mass of core material, i.e., about 0.017 kt per gram for uranium-235 and 0.019 kt per gram for plutonium-239, then the total energy available in the core is $M\epsilon$, and the efficiency, by equation (2.1), should be $E/M\epsilon$, where E is given by equation (2.7). However, this is not strictly correct, for in the derivation of this equation no allowance has been made for the depletion of the core material as fission proceeds. For low efficiencies this is, of course, not important, but a distinction will, nevertheless, be made by writing ϕ' for the value obtained using equation (2.7), so that

$$\phi' = \frac{E}{M\epsilon} \approx \frac{R^2\alpha^2\delta}{(\gamma - 1)\epsilon} \ , \tag{2.8}$$

where ϕ' may be related to the true efficiency, ϕ, by a relationship such as

$$\phi = \frac{\phi'}{1 + 1.2\,\phi'} \ , \tag{2.9}$$

sometimes referred to as the depletion correction.

If the tamper density, ρ_t, is not very different from that of the core, then, within a

moderate range of efficiencies, approximate allowance for the effect of the tamper may be made by a factor proportional to $(\rho_t/\rho_c)^n$, where n is less than unity. The limited applicability of the correction may be seen from the fact that it fails completely when there is no tamper, i.e., when ρ_t is zero. However, upon introducing this correction factor, with n = 0.5, into equation (2.8), the result is

$$\phi' \propto \frac{1}{(\gamma - 1)\epsilon} \quad R^2\alpha^2\delta \sqrt{\frac{\rho_t}{\rho_c}} \ . \tag{2.10}$$

The first factor on the right side is a constant, k, so that equation (2.10) reduces to

$$\phi' \approx kR^2\alpha^2\delta \sqrt{\frac{\rho_t}{\rho_c}} \ , \tag{2.11}$$

which is one form of the Bethe-Feynman formula. [redacted] Since the total mass of fissile material is known, the actual energy release can also be evaluated.

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By comparison with experimental determinations, to be described in Chapter 6, it has been found that while the Bethe-Feynman formula is a useful qualitative guide, it is not always quantitatively correct. For example, the so-called constant, k, varies with the yield and with the composition of the core material, e.g., either plutonium alone, oralloy alone, or combinations of both in various proportions. Hence, normalization procedures must be adopted when using equation (2.11). As an increasing amount of information has become available, it has been found possible to adjust the value of k, and also to make other semi-empirical corrections. Carefully applied, the Bethe-Feynman approximation has been used successfully to design bombs having a wide range of energies. For complex assemblies or where fine distinctions are sought, however, more exact methods of calculating efficiencies are used, e.g., the detailed procedure described earlier or the crits method given below.

Effect of Size and Compression on Efficiency

From an examination of equation (2.11) a number of general conclusions can be drawn concerning the factors affecting the efficiency of a nuclear explosion. In the first place, since the efficiency increases as R^2, it would be advantageous for the core to be large at the time of initiation of the fission chain. This can be achieved in practice by bringing together subcritical masses which are designed to contain a large total amount of fissile material. Thus, for a given compression (or for no compression), the efficiency would be expected to be

greater the larger the mass of the core material. This expectation has been confirmed in numerous tests.

Although compression will result in a decrease in R, this will be more than compensated for by the considerable increase in α^2, for the reasons given in Section 1.4. In addition, the effect of compression on δ must be taken into account; the more highly compressed the core material at the time of initiation, the further will be the distance the surface will travel before the supercritical system becomes just critical. Thus, increased compression should result in a marked increase of efficiency; that this is the case is shown very simply by comparing the yield from a gun-type weapon, in which there is no compression, with that of an implosion weapon.

The effect of increasing the compression in an implosion weapon is indicated by the data in Table 2.1 which are based partly on experiment and partly on calculation.

Table 2.1 Effect of Compression on Efficiency

Average Compression		Efficiency
Core	Tamper	(per cent)

Calculation of Efficiency by the Crits Method

Consider a system containing a mass M of fissile material under a compression C_c; let M_c be the critical mass of the material under these conditions with a specified tamper. Then the number of crits or critical masses, N, present is given by

$$N = \frac{M}{M_c} \qquad (2.12)$$

According to equation (1.8), however, M_c is proportional to $1/C_c^2$, and so if M_{co} is the critical mass of the uncompressed material, i.e., when $C_c = 1$, with the same tamper, in the assembled

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form, it follows from equation (2.12) that

$$N = \frac{MC_c^2}{M_{co}} \qquad (2.13)$$

From the general discussion of the Bethe-Feynman formula it was seen that increasing either the mass of fissile material or of the core compression results in an increase of efficiency. It is evident, therefore, from equation (2.13) that the efficiency of a weapon will increase with the number of crits present at the explosion time. This qualitative result is of considerable interest, but a more quantitative development is possible, e.g., by expressing α and δ as empirical functions of the number of crits.

The method used to calculate efficiencies by the crits method is to consider a specific core material, e.g., either oralloy or plutonium, and a given tamper. The efficiencies for various masses of core and a certain compression, which may be unity, are then calculated in any convenient manner, e.g., by the Bethe-Feynman formula. From the results, a curve expressing the variation of efficiency with the number of crits can be drawn. According to the arguments presented above, this curve should apply to all core-tamper systems of the same type, i.e., with the same core material (plutonium or oralloy) and the same ratio of the compressions (or densities) of core and tamper.

Since, for any core of mass M and compression C_c, the number of crits is given by equation (2.13), the efficiency of the corresponding fission weapon can be obtained directly from the curve. A different curve is used, of course, for each core material. Variations in the ratio of core-tamper compressions and in the neutronic thickness of the tamper are taken into account in estimating the critical mass. For composite cores, containing both plutonium and oralloy, semi-empirical adjustments are required to make the crits method applicable to such systems.

The crits method has been found to provide a rapid and reliable procedure for calculating efficiencies. Its main advantage over the Bethe-Feynman formula lies in the fact that the difficult and uncertain neutron theory calculations of α and δ for each case are avoided. The basic curve showing the variation of the efficiency with the number of crits is determined by applying the Bethe-Feynman formula to a simple system for which this formula is known to be reliable.

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2.2 Factors Affecting Efficiency

Effect of Impurities on Efficiency

It was seen in Section 1.2 that the presence of impurities in the fissile material results in an increase in the critical mass. Hence, the number of crits present in a given mass of fissile material will decrease as the proportion of impurity increases. As seen above, a decrease in the number of crits means a decrease of efficiency. Consequently, the efficiency of a weapon will suffer appreciably if nonfissionable impurities are present. For this and other reasons, as will shortly be evident, it is desirable that the fissionable material be as pure as possible. Some indication of the effects on the energy yield of plutonium-240 as an impurity will be given below (Table 2.4).

Effect of Predetonation on Efficiency

The time at which the fission chain is initiated is of paramount importance in determining the yield of a given weapon.

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There is a certain probability that the fission chain will be initiated during this period by a background neutron, but the chance that this will occur at optimum compression is very small. Consequently, it is essential that a neutron source, such as described in Section 1.5, be included to initiate the chain reaction at the proper time.

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The effect of predetonation* can be illustrated by reference to Fig. 2.2, in which the ordinates are either the number, N, of critical masses, i.e, crits, or α, the multiplication

*The term "predetonation" as used at LASL refers to initiation before maximum supercriticality. Preinitiation, used by some workers, would be a more appropriate term, but there appears to be little prospect of its general adoption.

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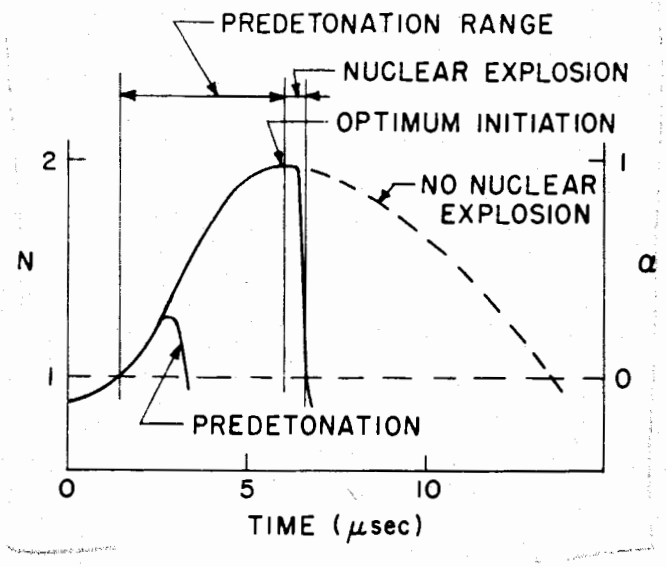


Fig. 2.2

rate, and the abscissae are elapsed time from the beginning of the assembly of a gun-type weapon or compression of an implosion weapon. The numerical values given for N and α are not exact and are intended merely as an indication of the changes which occur. The times, on the other hand, are fairly representative of an implosion weapon. The horizontal dotted line represents the situation for a system that is just critical, i.e., $N = 1$, $\alpha = 0$. Actually, the curves for N and for α as functions of time are somewhat different, and the maxima do not necessarily coincide. However, for the present qualitative discussion, a single curve is adequate.

At zero time the fissile material is subcritical, i.e., $N < 1$, and α is negative, but as compression (or assembly) occurs the value of N increases and α becomes positive, i.e., the system becomes supercritical. If, for some reason, there were no nuclear explosion, the fissile material would suffer decompression, due to its elasticity, after reaching the compression maximum, as indicated by the broken line in Fig. 2.2. In the case of a gun weapon, the parts may fly apart due to the impact.

The optimum yield will obviously be obtained if initiation occurs at the maximum of the curve, i.e., when N has its maximum value. It is at this instant, a few microseconds after compression starts, that the chain should be initiated by the special neutron source. In this event, the whole nuclear explosion will be over in 0.25 to 0.75 μsec, as stated in Section 1.4.

If a neutron entered the core in the period between that at which $N = 1$, $\alpha = 0$ and the maximum of the curve, i.e., while the system is supercritical but before maximum supercriticality is attained, an explosion would occur, but since N would not be as large as is possible, the efficiency will be low. Thus, in order to attain the highest efficiency, predetonation must be avoided. The same will also be true, of course, for postdetonation, i.e., initiation after the maximum of compression has been passed.

The variation of yield with time of initiation may be calculated by any of the methods given above for the determination of efficiency. All that is necessary is to introduce the values of N, α, ρ, etc., which are appropriate to the explosion time in each case. The values

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of ϕ will, of course, pass through a maximum, corresponding to the instant of maximum supercriticality.

Oralloy: Neutron Background and Predetonation Probability

In view of the loss of efficiency that would result from predetonation, it is necessary to consider the question of background neutrons, due to spontaneous fission and to the action of alpha particles on light nuclei. Nuclear reactions of the latter type are referred to as (α,n) reactions.

Because of the relatively low rates of spontaneous fission of both uranium-235 and -238, the number of neutrons due to this cause in oralloy is very small. Further, as a result of the very long half lives of both these isotopes, the rate of alpha particle emission is very low. The third naturally occurring isotope, uranium-234, has a half life of 2.35×10^4 years, and so emits alpha particles at an appreciable rate. This isotope is present to the extent of about 1.1 per cent in oralloy. However, the rate of neutron liberation in oralloy as a result of (α,n) reactions with light elements is not very large.

The total background neutron production in oralloy does not exceed about 2 neutrons/sec per kg.

If P_1 is the probability that a background neutron will be available in the fissile material during the period that the core is supercritical, and P_2 is the probability that this neutron will be able to start a fission chain, then the probability, P, of predetonation is given by

$$P = 1 - e^{-P_1 P_2} \approx P_1 P_2 \quad , \tag{2.14}$$

the approximate form being applicable when $P_1 P_2$ is small.

It should be pointed out that P_2 is a function of time and that both P_1 and P_2 depend, to some extent, on the position of the neutron and other variables. For the present purpose, which is to draw general conclusions only, specific values will be assigned to both P_1 and P_2. A neutron may either escape from the system altogether, or be captured in a nonfission reaction, or produce fission. Although the probabilities of these three processes are by no means equal, it will be postulated here that P_2 has an average value of 0.3 over the predetonation period, in all cases.

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Tamper and Initiator Background

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Plutonium: Neutron Background

With plutonium the situation as regards background neutrons is very different from that with oralloy. Not only is the spontaneous fission rate of plutonium-240 (an inevitable impurity)

high, but, in addition, the moderately short half life of plutonium-239 means a considerable rate of alpha-particle emission which can lead to neutron production by (α, n) reactions.

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The elements which have appreciable cross sections for (α, n) reactions are those with mass numbers of about 30 or less.

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It should be noted that the amounts refer to each individual element if it alone is present. If there are several present, as will usually be the case, then if c_i is the concentration of the element i in parts per million, the sum of the c_i/q_i values for all the elements must not exceed unity, where q_i for each element is that given in Table 2.2.

Predetonation Probability with Plutonium

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It is of interest to mention here that when the nuclear fission bomb was first planned, it was designed as a gun-type weapon, since it was felt that this would provide a simple and reliable method for rapidly attaining supercriticality. However, when plutonium became available in quantity, and the high background rate of neutron production due to spontaneous fission of plutonium-240 was discovered, a complete change of outlook was necessary. It was then that consideration was given to the much more difficult problem of converting a subcritical mass of fissile material to the supercritical system by compression in an extremely short interval of time by means of an implosion.

The chief difficulty anticipated in the design of an implosion weapon was the production of a shock wave having reasonably good spherical symmetry, so as to provide uniform and, hence, virtually instantaneous compression of a subcritical sphere of fissile material. When this problem was solved, by the methods to be described later, the smaller predetonation probabilities and the higher efficiencies attainable resulted in a concentration of attention upon weapons of the implosion type.

The smaller the permissible proportion of plutonium-240 in the fissile material, the shorter will be the exposure time, expressed in MWD/T, of the fuel elements in the production reactors (see Section 1.5). Consequently, material of low plutonium-240 content, i.e., with a low neutron background, will be both scarce and costly. It is desirable, therefore, in the design of implosion weapons to determine if plutonium of higher MWD/T value can be utilized.

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Effect of Background Neutrons and Material Dilution on Yield

The estimates of predetonation probabilities due to the presence of plutonium-240 have been intended only to give an indication of their orders of magnitude.

in Chapter 4.

In addition to the yield loss from predetonation, i.e., the predetonation probability, which is statistical in nature and can be determined only as an average loss for a large number of bombs, there is another loss which occurs for each individual bomb. This is usually referred to as material dilution, and is due to the dilution of the plutonium by the less reactive 240-isotope.

The values are relative to the efficiency for plutonium containing none of the 240-isotope.

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Fissions in Tuballoy

Although a fission chain reaction cannot be sustained in uranium-238, this isotope is fissionable by fast neutrons having energies in excess of about 1 Mev.

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2.3 Implosion Asymmetry and Efficiency

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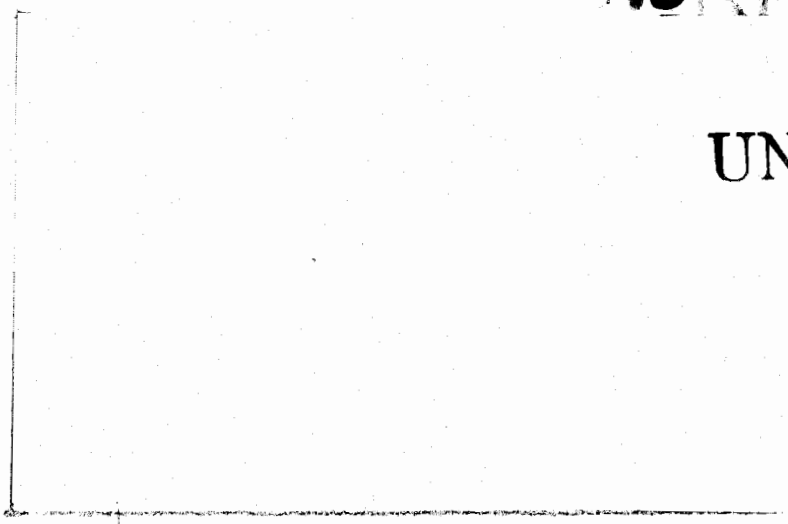
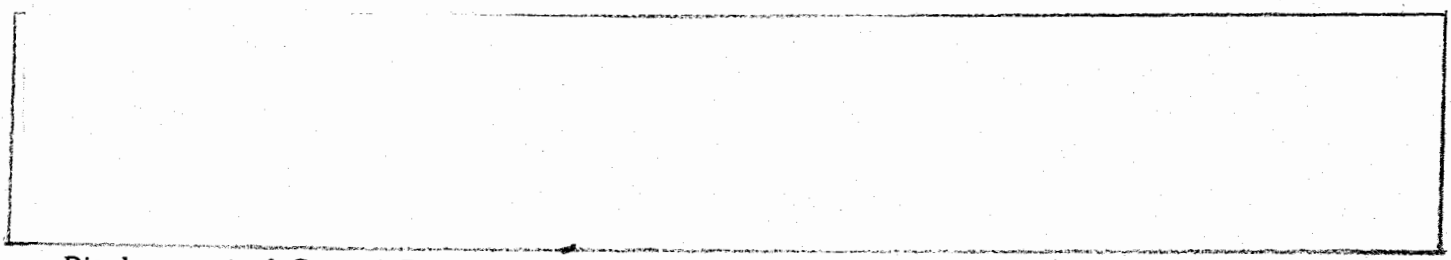


Fig. 2.5

Fig. 2.6



Displacement of Central Ball

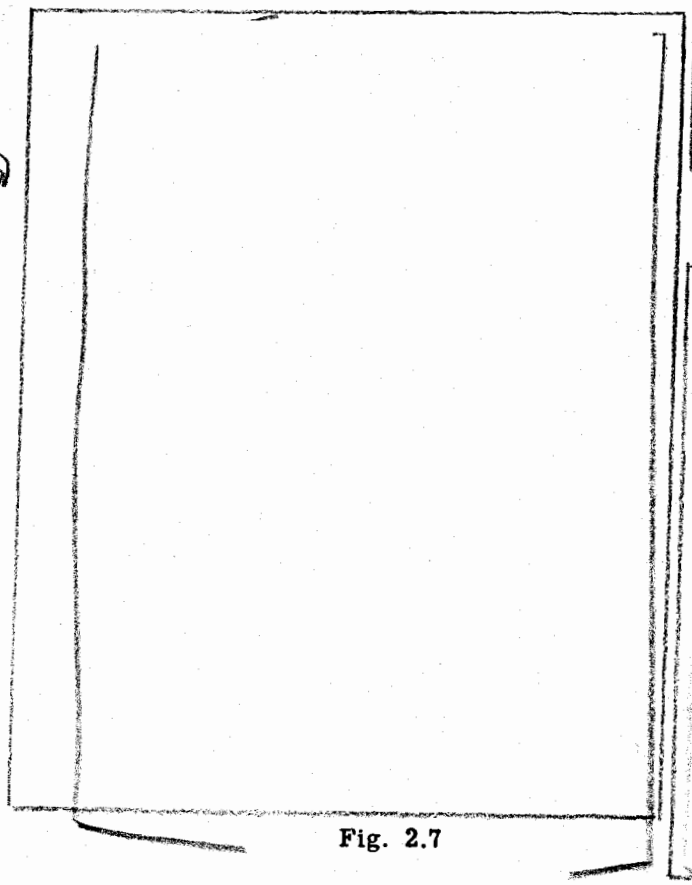
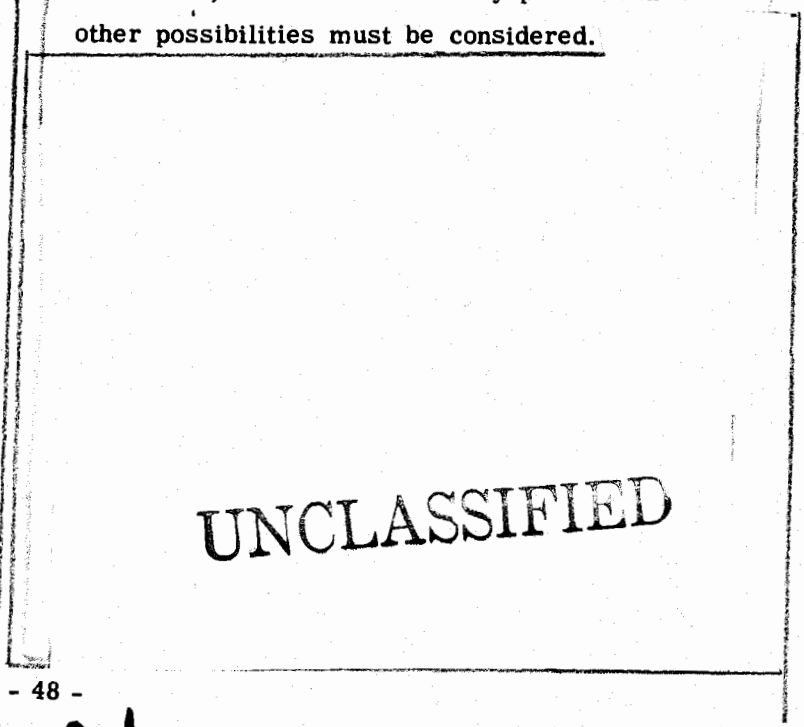


Fig. 2.7

It will be seen later, that this is not very probable and other possibilities must be considered.



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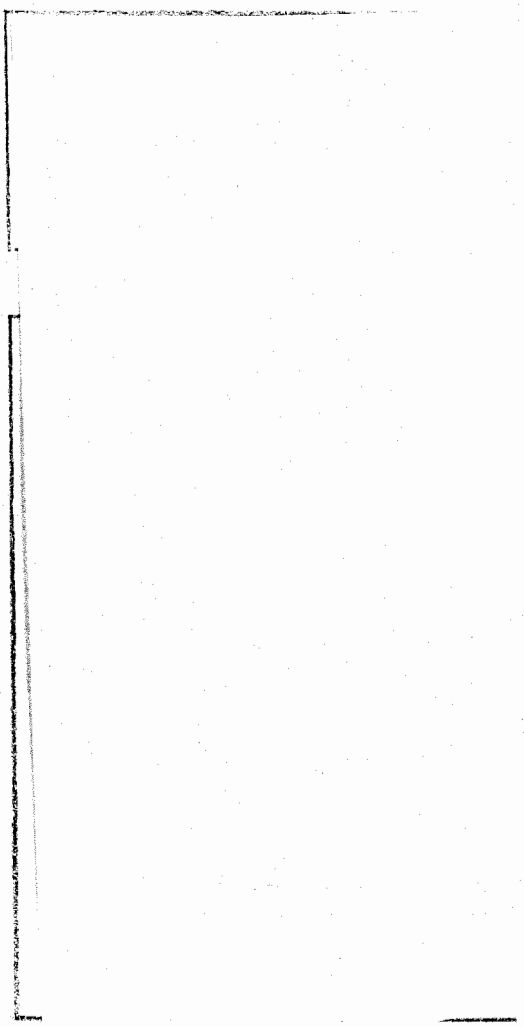


Fig. 2.8

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Chapter 3

General Design of Fission Weapons

3.1 Implosion Weapons

Components of Implosion Weapons

In brief, an implosion weapon is designed to provide the greatest possible symmetrical compression of the fissile (core) material and, at the proper time, i.e., as close as possible to maximum compression, to introduce neutrons which will initiate a fission chain reaction. The necessity for symmetry in the compression arises from the fact, considered at the end of the preceding chapter, that any appreciable asymmetries lead to a decrease of efficiency and, hence, in yield of the explosion.

The general principle whereby the foregoing requirements are achieved can be explained by means of Fig. 3.1; this is a scale drawing of a section through the original form of the implosion bomb which was detonated at the Trinity test and at Nagasaki in 1945, and in the Bikini tests of 1946.

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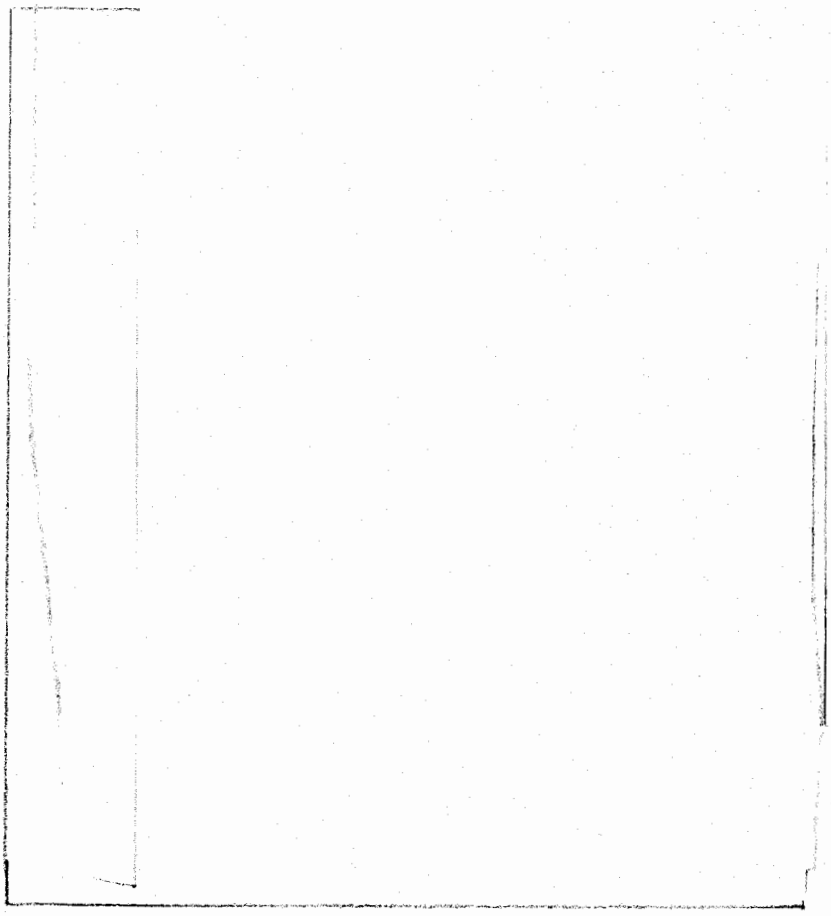


Fig. 3.1

The purpose of the lenses, as will be explained shortly, is to convert the usual divergent detonation (or explosion) wave arising from an explosive charge into an inward-traveling, spherical,

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convergent (or implosion) wave. In order to insure maximum symmetry of the implosion wave the spread of firing times over the surface of the sphere must be very small.

This is largely because it appears that when only a limited space is available, it is better utilized in other ways, as will be explained later.

The implosion shock wave travels through the tamper and then strikes the core of the fissile material. As a result of the steadily decreasing volume into which the shock moves, there is a greatly increased concentration of shock energy, and a corresponding increase in compression, as the wave travels toward the center. The highest compression is thus attained in the core where it is needed. As the core is compressed in this manner the previously subcritical mass becomes supercritical and a divergent fission chain can be maintained. When the shock wave arrives at the center of the core, it brings about activation of the neutron source or initiator. Consequently, neutrons are introduced into the core and the fission chain is initiated at a time close to the instant of maximum compression. As already seen, maximum compression is a reasonable criterion for optimum energy yield.

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The large uncertainties indicated are due to differences in the results obtained by the two standard methods for determining bomb yields (see Chapter 6).

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It is of interest to give some idea of the time scale in a fission bomb explosion. The elapsed time between firing the detonators and the initiation of the fission chain by the central neutron source is called the transit time.

Fig. 3.2

Principle of the Lens System

The fundamental laws underlying the propagation of detonation waves are analogous to those

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applicable to acoustical and optical waves. In fact, the laws of geometrical optics can be used to describe the behavior of detonation waves. Just as light waves are refracted when they travel from one medium to another in which the speed of light is different, so a detonation wave can be made to undergo refraction by using two explosives with different detonation velocities. The ratio of these velocities, as with light, is called the index of refraction of the system.

A properly designed combination of an inner portion consisting of a slow explosive, i.e., one having a moderately slow speed of detonation, and an outer portion of a faster explosive is able to produce a convergent (or implosion) wave (see Section 4.3).

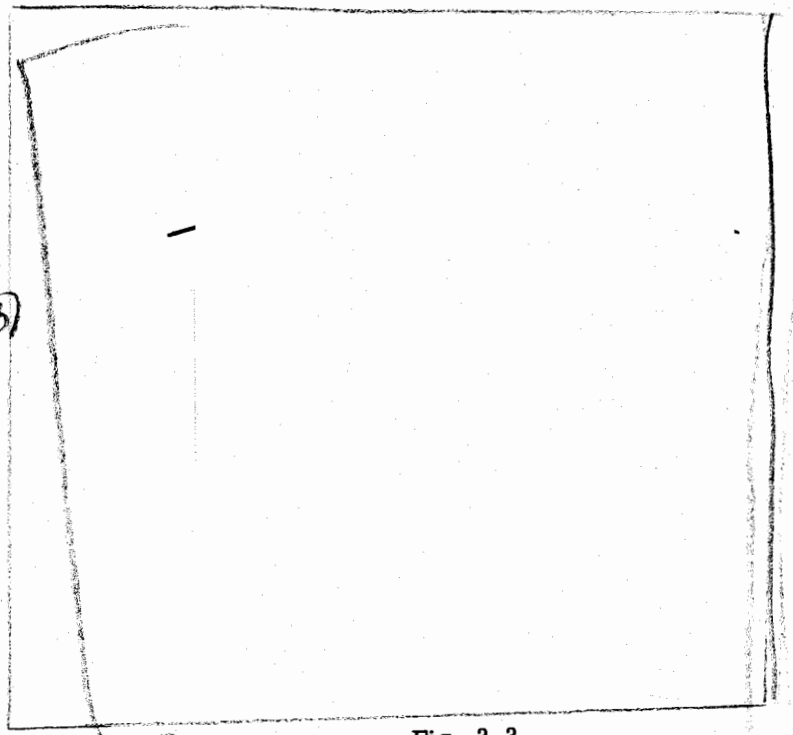


Fig. 3.3

The fast component surrounds the slow one, and its lower surface is concentric with the desired implosion wave. The combined system can act as a lens to produce spherical convergence of a detonation wave to a desired focus.

If a detonation is started at the apex of the slow component, the detonation wave will travel faster over its surface, where it is in contact with the fast component, than in its interior. As a result there will be a lag in the front of the detonation wave within the slow component, as indicated by the dotted lines in Fig. 3.3; this shows a number of successive positions of the detonation wave as it moves toward the center of the bomb. If the lens is properly designed, this wave will be concentric with the bomb and hence with the sphere of fissile material located at its center. If the convergent detonation waves from the various lenses reach the inner surface of the lens system simultaneously, they will join together to form a complete spherical implosion wave. This will then travel without appreciable change in form, but with increasing energy, through the uniform HE inner charge.

3.2 General Design Modifications

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When the shock wave produced by the detonation of the HE inner charge enters the tamper, the latter moves forward, with the attached pusher, through the air space with increasing velocity. As a result, when the tamper reaches the core, it strikes the latter a tremendous, hammer-like blow. More energy is thereby transferred to the core, which is consequently more highly compressed than would be the case in the absence of a free run.

Fig. 3.4

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Composite Cores

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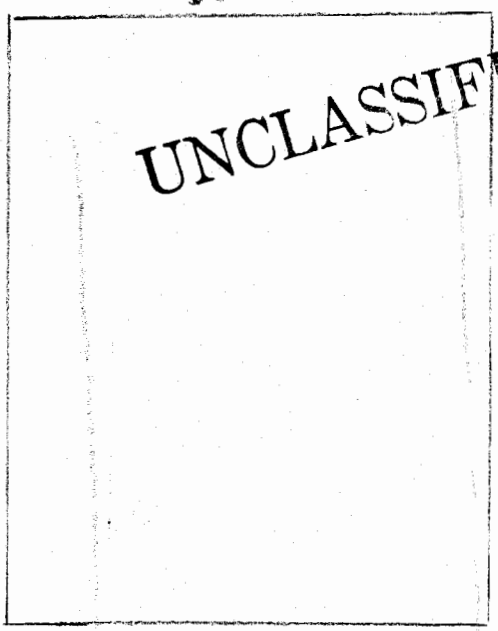


Fig. 3.5

This results from the fact that plutonium produces, on the average, about 2.9 prompt neutrons per fission, whereas uranium-235 yields about 2.5 neutrons. Because its chances of escape are less, a neutron originating in the center of the fissile core has a greater probability of causing fission than one produced in the outer portions. The over-all fission rate and energy yield are thus markedly dependent on the fission rate near the center of the core. Since plutonium produces more neutrons pe fission than does oralloy, it will have a higher α value, i. ., a high multiplication rate. Consequently, in a spherical co e consisting of a plutonium center and an oralloy outer region, the neutron density in the latter will be appreciably greater than if the core consisted entirely of oralloy.

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Fig. 3.6

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Fig. 3.7

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3.3 Design of Implosion Bombs

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The HE System

The design of an implosion bomb involves a combination of theoretical hydrodynamic calculations, performed with the aid of computing machines, empirical relationships, based on previous experience, and experimental tests of various components and assemblies. It is not necessary to treat the problem in detail here, and a general outline of the approach used will be sufficient.

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Fig. 3.9

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In actual practice, some variation is possible, as will be seen in Chapter 4.

Pusher and Tamper

The next component to consider is the pusher. As stated earlier, this serves to smooth out asymmetries in the implosion wave, and it may provide some additional tamping by scattering neutrons back into the core.

In the HE systems now in general use, the irregularities in the implosion front are relatively small.

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General Considerations

As indicated at the outset, the first step in the design of a new weapon, using accepted principles, is to make machine and other calculations based upon hydrodynamic theory and empirical data obtained in various tests and experiments. If the general results of these calculations appear promising, then the individual components are designed and tested individually and finally in various assemblies. The details of design and testing will be discussed in subsequent chapters.

It has been assumed, so far, that established and proven concepts are used in weapon design. From time to time, however, new ideas are proposed or old ones are revived.

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They are, of course, subjected to both theoretical and experimental tests before

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a decision is made concerning their value and possible incorporation in new weapons. Some of these new principles will be examined below.

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3.4 Gun-Type Weapons

Components of Gun-Type Weapons

The design of gun-type weapons is a much simpler problem than is the case for implosion weapons. The principle of the gun-type design may be understood from Fig. 3.10.

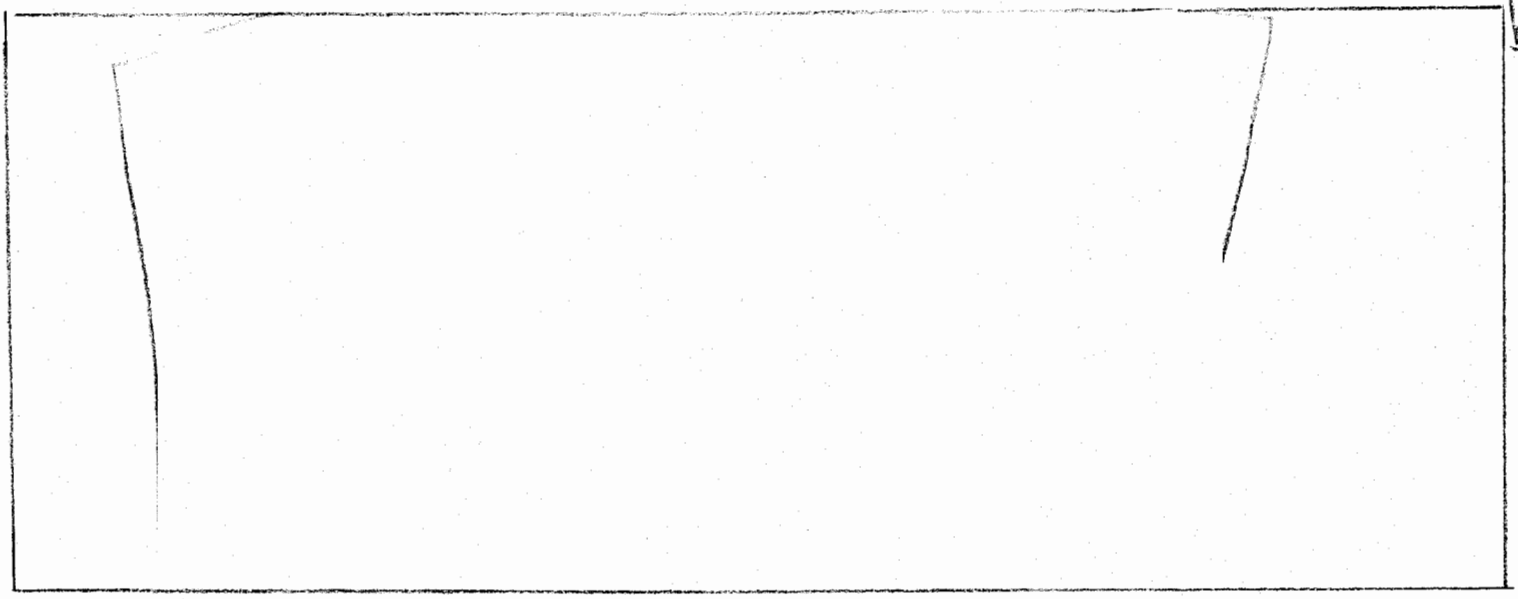


Fig. 3.10

In order to explode the weapon, the detonator, at the left end of Fig. 3.10, is fired and this causes ignition of the propellant. When it is completely seated, the impact activates the polonium-beryllium initiator and neutrons are injected very close to the instant of maximum supercriticality. The fission chain is initiated and the weapon explodes.

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The tamper in the gun-type weapon serves two functions which are the same as in implosion weapons, i.e., neutronic and inertial tamping.

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The efficiency of a gun-type weapon is considerably less than that of an implosion weapon employing the same amount of fissile material. The absence of compression in the gun-type weapon is the primary reason for this difference.

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While the fundamental design principles of the gun-type weapon have remained essentially unchanged, a number of improvements have been introduced and proposed. These will be referred to in Chapter 5, where the constructional details of various forms of this weapon are described.

Design of Gun-Type Weapons

Because of their lower efficiency and, apparently, limited range of energy yield, as compared with implosion bombs, the design of gun-type weapons has not received great attention.

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This fissile material produces more neutrons per fission than does uranium-235 (see Table 1.1) and loses less in non-fission captures, and so it would give a higher efficiency.

Other factors, such as the nature of the tamper, which affect the efficiency of the chain reaction and the range of an artillery shell, are also being investigated. As a result, there has been a revival of interest in gun-type weapons for various special purposes.

3.5 Uranium-233 in Fission Weapons

Properties of Uranium-233

Although uranium-233 is as yet obtainable only in relatively small quantities, its nuclear properties are of interest in connection with fission weapon design. It is produced in reactors, by neutron capture in thorium, followed by two moderately rapid stages of beta decay. The uranium-233 is then separated from the thorium by chemical methods. Thus, the production of uranium-233 is somewhat similar to that of plutonium, and it may be inferred that its cost would be approximately the same. However, the problem of spontaneous fission in plutonium, due to the presence of the 240-isotope, is virtually negligible in uranium-233 (see Table 1.2).

Experiments with uranium-233 have shown that its critical mass in spherical form, either bare or with an infinite tuballoy tamper, is approximately the same as for plutonium (see Table 1.1). The higher density of uranium, however, makes the critical volume somewhat less. Although the number of neutrons produced per fission in uranium-233 is not much greater than in the 235-isotope (oralloy), the ratio of the fission cross sections is about 1.6 in favor of the former. Further, the neutron loss due to nonfission capture is less in uranium-233. As a result, this material has interesting possibilities for use in fission weapons.

The neutron background in uranium-233 is due almost entirely to (α, n) reactions with light element impurities; the spontaneous fission rate, including that of other uranium isotopes present, is very small. Since uranium-233 has a much shorter half life (1.62×10^5 years) than uranium-235, the rate of alpha-particle emission is greater. Hence, for the same light element

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impurities as in oralloy, the background is estimated to be 35 to 50 neutrons/sec per kg, as compared with a total of 2 neutrons/sec per kg for oralloy. Nevertheless, the former value is very much less than for 200 MWD/T plutonium, which has a background of 16,000 neutrons/sec per kg.

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3.6 Boosting

General Principles

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It should be noted that the contribution of the energy released in the thermonuclear reaction is small compared with that produced by fission.

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Finally, the average number of neutrons released in fission by 14-Mev neutrons is more than four. Since this is larger than the normal values given in Table 1.1, there is a consequent further addition to the neutron population.

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The ratio of the efficiency (or yield) of a boosted device to that for the same device without boosting, is called the boosting factor.

Tests of Boosting

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The first test of boosting was made in the Item shot (Greenhouse, 1951).

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Chapter 4

Components Design and Testing: The HE System

4.1 Introduction

In the preceding sections, the general fundamental principles involved in the design and operation of nuclear weapons have been discussed. The present chapter and the next one will be devoted to a description of some detailed aspects of the design, production, and testing of the various components of weapons of different types. Before proceeding with this, however, it will be worth while to review certain historical phases in the development of implosion bombs.

The outer diameter (60 inches) of the earliest implosion weapons was determined by the size of a B-29 bomb bay.

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After the development of the first stockpile bombs, the Mark 3 and Mark 4, both now obsolete, two directions were considered in which improvement in design appeared possible. First, to decrease the size without any great loss in yield and, second, to increase the yield for a given size.

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* Because of its size, the first implosion bomb was called the "Fat Man" (or FM), in contrast with the first gun weapon, which was thinner and longer; the latter was called the Little Boy (or LB).

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4.2 The Detonator System

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General Design Principles

In order to obtain a spherically symmetrical implosion, it is necessary that the maximum possible simultaneity be attained in the firing of the detonators which initiate the explosion wave in the lenses. Consequently, it was necessary to design special detonators and a suitable firing system that would give an extremely small spread in firing time.

The principles developed for the detonator systems of the earlier bombs are still used, although there have been marked improvements as regards weight, size, efficiency, and over-all design. The actual firing is performed by passing an electrical pulse of relatively high energy through a short, thin wire, called a bridge wire. As a result of the sudden and large increase of temperature, the wire vaporizes extremely rapidly and produces a shock wave.

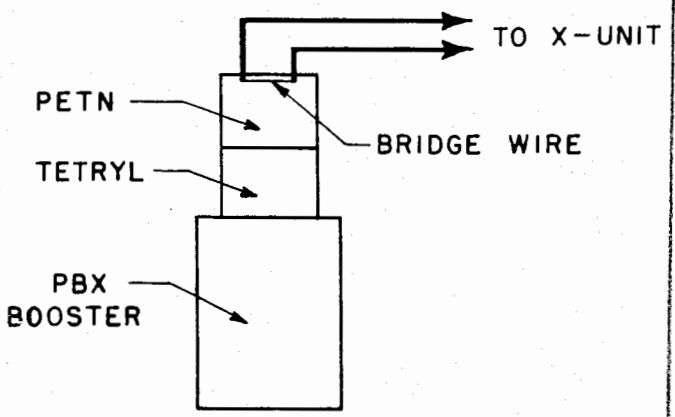


Fig. 4.1

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The X-Unit

The electrical firing system is called the X-unit; its action depends on the charging of a bank of condensers to a high voltage, and then discharging them at firing time through the detonator bridge wires, in parallel, by means of a triggered spark gap or a mechanical switch.

*Increase in packing density increases the energy yield (or power) of an explosive, but makes it less sensitive to detonation.

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Fig. 4.2

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Detonator Types

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As a result of field tests by the military, it was found that the 1E22 detonator would not withstand rough handling. Consequently, some constructional changes have been made to provide additional mechanical strength. The new form is being called the 1E25 and it is proposed for use in conjunction with ring lenses in the TX-13 bomb which is not yet in production.

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As a result, the 1E23 was produced.

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A section through the middle of a 1E24 detonator is shown in Fig. 4.3.

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Fig. 4.3

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Since simultaneity is an important requirement of a set of detonators, special care is taken to insure uniformity in the composition and density of the explosive materials. The dimensions of these substances in the detonator and of the bridge wire must be exact, within close tolerances. The necessity for careful control of all components involves numerous inspections at all stages of production.

Detonator Testing

Prior to assembly, the parts of a detonator are gaged and the head, containing the electrical connections, is examined radiographically to detect internal faults, as will be described shortly. When assembled, the detonator is inspected visually, important external dimensions are gaged, and the resistance of the bridge wire is measured. A selected number of detonators are then subjected to destructive testing.

Three types of firing tests are performed; these are determination of (a) simultaneity, (b) transit time, and (c) threshold (or minimum) voltage required to detonate the bridge wire. The detonators are manufactured in lots of about 1250 under conditions which should make them as nearly identical as possible. Of each lot, 132 are selected at random for destructive testing: 112 for simultaneity, 10 for transit time, and 10 for threshold voltage. This number is regarded as being large enough to represent a good sample.

Simultaneity is investigated by the rotating mirror camera method (RMC)* which will be explained with the aid of Fig. 4.4. A set of 28 detonators and two bare bridge wires are placed horizontally, in a direction perpendicular to the plane of the paper. The purpose of the two bridge wires is to provide fiducial or reference points for timing purposes. The detonators and bridge wires are attached to a special X-unit of precision construction, so that they can be fired simultaneously. When the shock wave emerges from the detonator after firing, light is produced and this is focused by the objective lens system onto a horizontal slit, parallel to the line of detonators.

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*This rotating mirror camera is also called a "smear" or "streak" camera or a Bowen-type camera; however, the original Bowen device was not a smear camera, but a high-speed framing camera using a rotating mirror.

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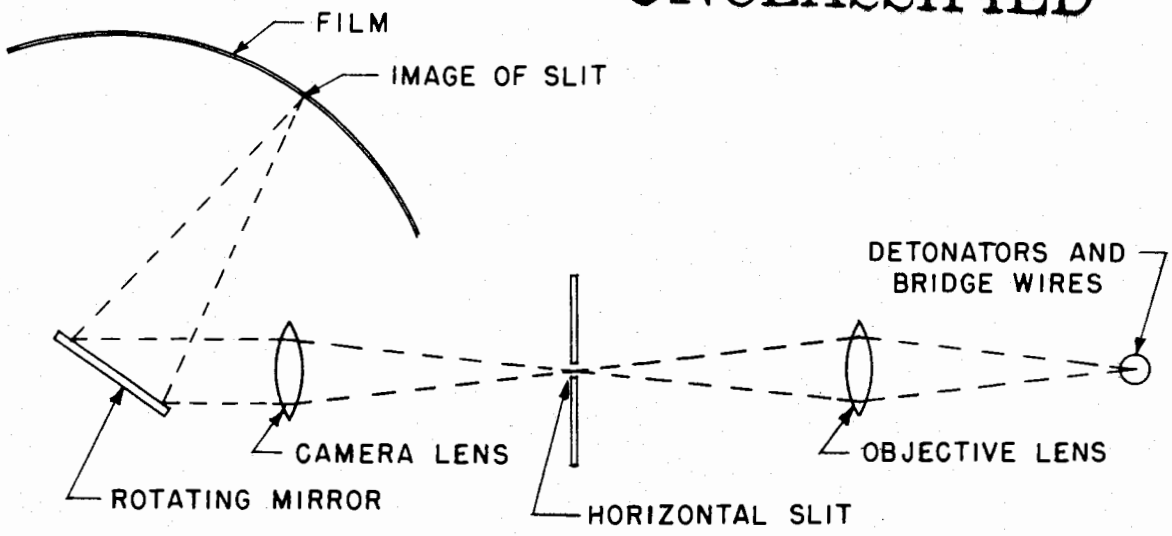


Fig. 4.4

As the mirror rotates, the first light picked up is that from the two bare bridge wires, and these leave traces (or streaks) on the film, which appear after development. There is then an interval during which the detonation waves are traveling through the 28 detonators. As each wave emerges from the face of the detonator, the light emitted produces its effect on the film. If all the detonators fired absolutely simultaneously, then all detonator streaks would start at precisely the same level on the film, and any deviations from simultaneity can be readily detected. From a knowledge of the rate of rotation of the mirror, and the distance from it to the film, displacement of the streaks on the film can be converted into intervals of time.

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The procedure described above is carried out with four groups of 28 detonators, and failure of any one of the 112 to fire, or inability to meet the simultaneity specifications given above, results in rejection of the complete lot of 1250 or so detonators. It is for this reason that the lots are not made too large, yet sufficiently large for a reasonable number to remain after removal of samples for testing.

Although the primary purpose of the rotating mirror camera procedure is to test simultaneity, it can be used to determine the time elapsing between bursting of the bridge wire and

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the production of shock-induced light at the detonator face. While the information obtained in this manner is useful, it is not regarded as sufficiently reproducible for use in comparing batches of detonators or finding if changes have occurred in storage. For the precise determinations of transit time the cable timing system (CTS) is employed.

In the CTS procedure only one detonator is used in each measurement, and determinations are made with 10 detonators from each lot. A schematic diagram of the circuit used is shown in Fig. 4.5. When the switch is closed, the firing condenser causes a high-voltage discharge

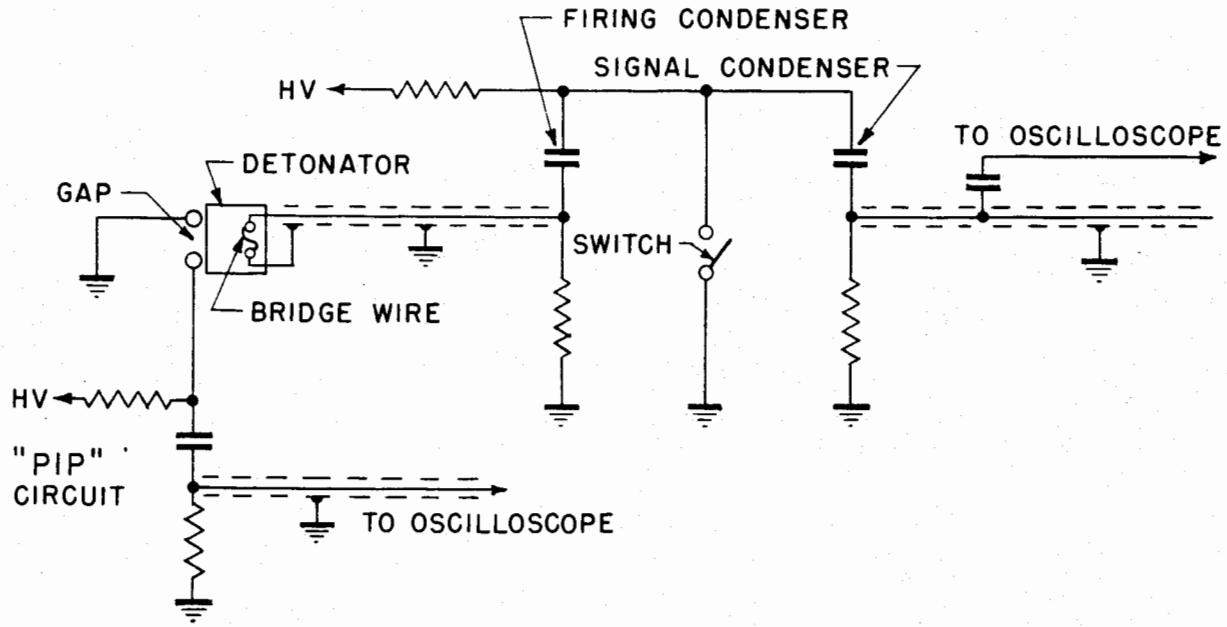


Fig. 4.5

to pass through the bridge wire of the detonator, at the left, and simultaneously, the discharge of the signal condenser, of smaller capacity, sends a signal along the coaxial cable at the right. This is recorded on an oscilloscope to indicate the time of closing the circuit. The signal continues to travel to the end of the coaxial cable and upon its return it will produce a second indication on the oscilloscope The distance between the indications represents an exact time interval which is dependent on the dielectric properties of the coaxial cable.

In the meantime, the bridge wire will have exploded and initiated the detonator. When the detonation wave reaches the front of the detonator an ionized region is formed which allows current to pass across a gap and so permits the discharge of the condenser in the "pip" circuit. As a result, a signal is sent to the oscilloscope and the record appears

somewhat as in Fig. 4.6. Since the fixed time interval is known, the transit time of the de-

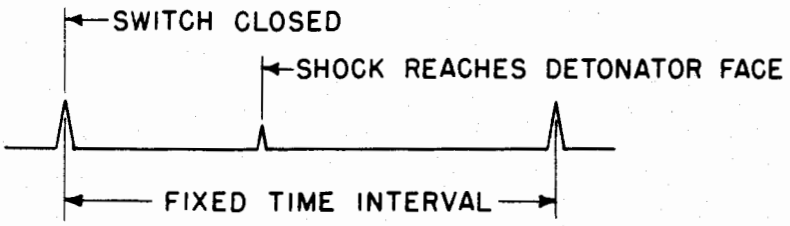


Fig. 4.6

tonator, between closing the firing switch and the appearance of the shock wave at the face, can be determined.

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It should be noted that the transit time includes the interval between closing the switch and the explosion of the bridge wire; this differs somewhat from the value obtained by the RMC method, since in the latter case the fiducial signal is provided by the exploding bridge wire.

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If the detonator fails to fire, it is replaced by another, as the bridge wire will undoubtedly have been destroyed.

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Radiographic Testing

In the radiographic testing of detonators, X-rays of relatively low voltage (40 to 120 kv) pass through the object to be examined and then fall on a radiographic film, which is subsequently developed. The procedure is, in fact, exactly similar to that employed in medical and dental radiographs. The plastic head of every detonator, which contains the bridge wire and its connections, is examined by this method for internal defects that cannot be seen or detected in any other way. Two radiographs are taken from two directions at right angles, so that the positions of various components can be determined.

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Thus, in the noncritical region some reliance is placed on the judgment of the observer.

Environmental Tests

Because detonators may be required to operate under extreme conditions of temperature, humidity, altitude, etc., as dictated by military expediency, they are subjected to a variety of so-called environmental tests. For example, they are test fired at both very low temperatures, e.g., -65°F and sometimes as low as -90°F, and at very high temperatures, e.g., 165°F, after being maintained at these temperatures for some time. The effects of short exposures to very high temperatures, to which a nuclear fission warhead in a guided missile might be exposed, are also examined. The detonators must operate at high altitudes, up to 35,000 feet,* and over a considerable range of humidities.

The effect of storage in various climates is investigated by artifical simulation of the conditions. This includes temperature cycling, equivalent to the day and night variations that might be encountered in arctic, tropic, and desert regions.

Extensive and continuous testing is performed to determine the effect of temperature and humidity on the life of a detonator in storage. This insures that stockpiled detonators have not deteriorated. Non-propagating storage cases have been designed, so that if one detonator is accidentally set off, the others in the case will not be affected.

As an aspect of the environmental testing, detonators have been subjected to gasoline fires and hot oil. Although burning occurred, there was no explosion. The effect of impact has been studied and the results show that the detonators are remarkably safe. Some tests have been made with the HE system of a Mark 7 having the projecting 1E23 detonators installed. Five complete HE assemblies were dropped from a height of 40 feet on to a thick steel slab backed

*The firing system (X-unit) will not function at substantially higher altitudes, because leakage occurs due to electrical discharges at low pressures.

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by concrete. A few detonations of a low order occurred, which may have been due to the fast component (Composition B) of the lenses. The lenses and HE inner charges suffered severe mechanical damage; so also did many of the detonators but they did not explode. In a similar impact test with five Mark 12 HE assemblies, with buried (1E24) detonators, there was no indication of either detonation or burning of the detonators or HE inner charge, although mechanical damage was considerable.

4.3 The Lens and Inner Charge System

Lens Design

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Fig. 4.9

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*Although this is true in theory, it will probably not hold, in practice, in the regions very close to the point of detonation.

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Fig. 4.10

Number of Lenses

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*Figs. 4.10 and 4.11 are somewhat distorted because they attempt to represent a spherical surface on a plane paper.

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Fig. 4.12

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The Ring Lens

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Fig. 4.13

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Fig. 4.14

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Fig. 4.15a

Fig. 4.15b

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Fig. 4.16

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HE Components of Lenses

The fast-explosive component, which has remained almost unchanged throughout the development of implosion weapons, is known as Composition B. It consists of 60 parts by weight of RDX and 40 of TNT (trinitrotoluene).* In addition to being a stable but powerful explosive, it is readily available. The detonation velocity of Composition B in rod form, i.e., the so-called "stick rate," is about 7900 meters/sec, and although explosives with higher detonation velocities are available, so that the refractive index may be increased, they have various drawbacks, with regard to stability, fabrication, handling, availability, etc., as compared to Composition B.

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*In order to introduce some system into the naming of explosives, it has been proposed to refer to Composition B as cyclotol 60/40. By convention, a name ending in "ol" indicates the presence of TNT.

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Fabrication of Lenses

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The amount of machining done is the minimum necessary to remove extraneous material.

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A highly significant aspect of the machining method of fabrication is its great flexibility. Whereas in the so-called precision casting procedure any change in design or dimensions required new and expensive molds, many such changes can now be very rapidly made by adjustment of the cutting tools.

HE Inner Charge

The prime purpose of the HE inner charge, often abbreviated to I.C., is to transmit the spherically convergent implosion wave, produced by the lens system, with increased energy, so as to cause maximum compression of the core of the bomb. In addition, it has been found that, if of sufficient thickness, the HE inner charge serves partially to smooth out some of the local irregularities which inevitably exist in the detonation wave at the time it leaves the lens system.

Apart from the obvious requisites of uniform density and composition, and the absence of air bubbles, voids, cracks, etc., the explosive material of the I.C. should be one of high power and of good stability. In the Mark 5, 6, and 18 bombs, Composition B is used, but in the Mark 7, this has been changed to a new mixture, called cyclotol 75/25, consisting of 75 parts by weight of RDX and 25 parts of TNT. Weight for weight, this provides about 13 per cent more compressive energy than does Composition B. Cyclotol 75/25 will also be used in the Mark 12 system. [redacted]

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[redacted] This is a provisional measure, pending a final decision concerning the exact dimensions of the tamper. [redacted]

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Improvements in the HE inner charge system may come from the introduction of a more powerful explosive or from better fabrication methods. As regards the former, a mixture called Octol, consisting of 75 per cent of the explosive HMX (cyclomethylene tetranitramine), which is related to RDX, and 25 per cent of TNT, is being considered. Because of the high density (1.91 g/cc) of HMX (as compared with 1.81 g/cc for RDX), it is possible to include a greater mass in the same volume.

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At the present time HMX is expensive and is not available in sufficiently large amounts for wide usage.

A study is being made of the possibility of adapting a plastic bonded explosive (PBX) for HE inner charges. The main advantage would be that the charges could be rapidly and economically fabricated by vacuum pressing of a molding powder consisting of RDX and a plastic. The product would be more uniform than that obtained by casting and it would have improved mechanical properties. Ultimately, precision molding might be possible, so that machining to exact dimensions would be unnecessary. Actually there are many problems still to be solved before PBX could be seriously considered as a substitute for Cyclotol (or Octol) in HE inner charges.

One of the drawbacks to the use of the regular PBX is that the polystyrene is an inert constituent and contributes essentially nothing to the explosive power. This might perhaps be overcome by means of a nitrated plastic material that would itself be an explosive. A study is being made of substances which could serve this purpose.

4.4 Testing HE Lenses and Inner Charges

Physical, Analytical, and Radiographic Tests

Both HE lenses and inner charges are manufactured from materials, supplied by outside producers, which must meet certain specifications. Standard quality control techniques are used at all stages of fabrication, and acceptance tests are applied to the finished products. The latter are thoroughly tested to insure uniformity in composition, and to determine if they have certain required characteristics. The testing procedures may be considered under four

main headings: a) physical methods, (b) analytical techniques, (c) radiographic methods, and (d) test firing. In addition, environmental tests, similar to those described for detonators, are made with samples of lens systems and inner charges.

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Analytical techniques are destructive in nature and are concerned with a detailed examination of a number of samples obtained from different parts of a single piece. Determinations are made of density and composition to insure uniformity. These are, of course, important factors in connection with the symmetry of the spherical implosion wave.

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Radiographic methods are employed both for quality control and to determine acceptability. They are nondestructive and are consequently applied to all finished products, as well as in some intermediate stages. Because the heavy element barium is rather opaque to X-rays, radiations

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Inner charges are examined radiographically for cavities, impurities, and defects of various kinds. The whole of the inner charge is important and so there are no noncritical regions. Since inner charges are not subjected to routine firing tests, as are lenses, the radiographic procedure acquires special significance. However, the performance (or quality) of inner charges is determined indirectly in the course of other measurements, to be described below.

The radiographic technique is primarily applicable to the detection of discrete defects having definite boundaries.

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For a given material, this absorption will depend on the product of the thickness and density; thus, it may be possible to detect, in a nondestructive manner, gradual changes of density which cannot be observed radiographically.

Test Firing of HE Lenses

The purpose of test firings is to determine the transit time of a lens, i.e., the time for the detonation to travel from the face of the detonator to the lower face of the lens, and also to study the variations, if any, in emergence time of the shock wave at points across the face. For this test, anywhere from 2 to 10 per cent of the lenses of a given batch are selected so as to form a representative sample.

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Each gap forms part of an electrical circuit, so that when the shock front reaches the gap, the ionization produced causes a condenser to be discharged and a signal is transmitted to a rasterscope (or raster oscilloscope). This instrument gives a series of traces, each successive one below the other, over a period of time; accurate time interval pulses are superimposed on the rasterscope pattern. A schematic representation of the electrical circuit is given in Fig. 4.18.

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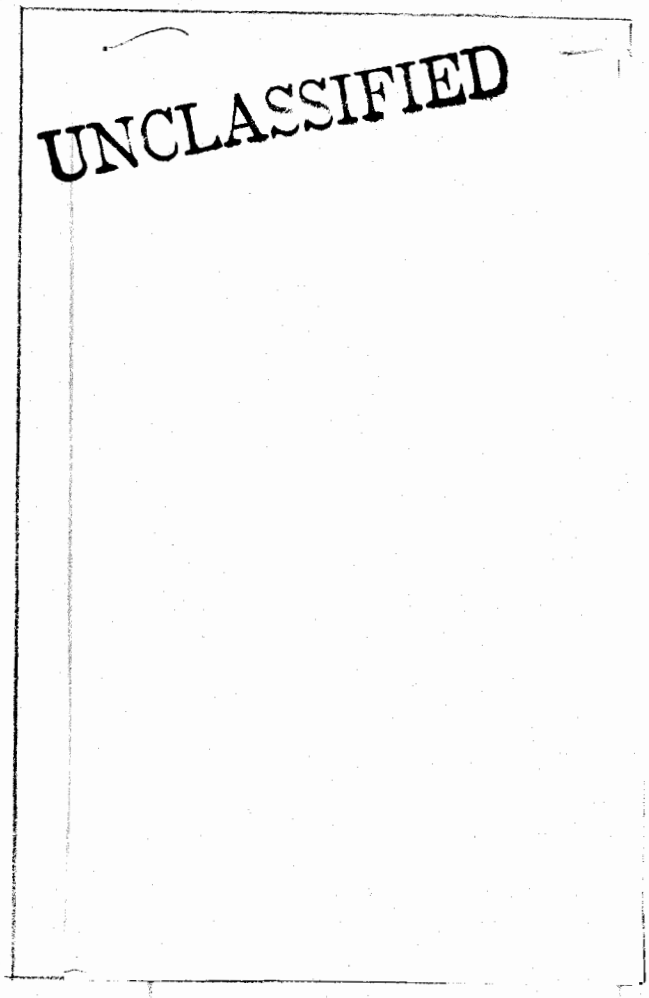


Fig. 4.17b

When the detonator is fired, the ionization due to the shock wave emerging from its base discharges one condenser, and this causes a deflection on the rasterscope trace. Then as the wave proceeds and emerges from the face of the lens, the second condenser is discharged, and a second deflection appears.

The distance between the two deflections on the trace, which is recorded by means of a camera, is then a measure of the transit time of the detonation wave through the lens. The actual transit time is obtained by making use of superimposed time pulses on the rasterscope trace. Some experimental values of transit times for various HE systems are given in Table 4.1 (below).

Simultaneously with the performance of the foregoing measurements, of transit times, the emergence times of the luminous detonation front at points across the lens face are being studied by means of rotating mirror (streak) camera. The procedure is exactly similar to that described in Section 4.2, for the testing of detonators.

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The slit shown in Fig. 4.19 is arranged so that the camera picks up the light from a strip across the middle of the face of the lens.

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If the luminosity appeared at exactly the same instant across the whole lens face, the developed film would show a dark streak with a sharp, straight boundary. Actually, because of the variations in emergence times of the shock front, the boundary shows irregularities. By magnifying the image from the film, it is possible to determine accurately the emergence times at a series of points across the lens face, with reference to the earliest emergence time. The results are then represented graphically with the time as abscissae and the

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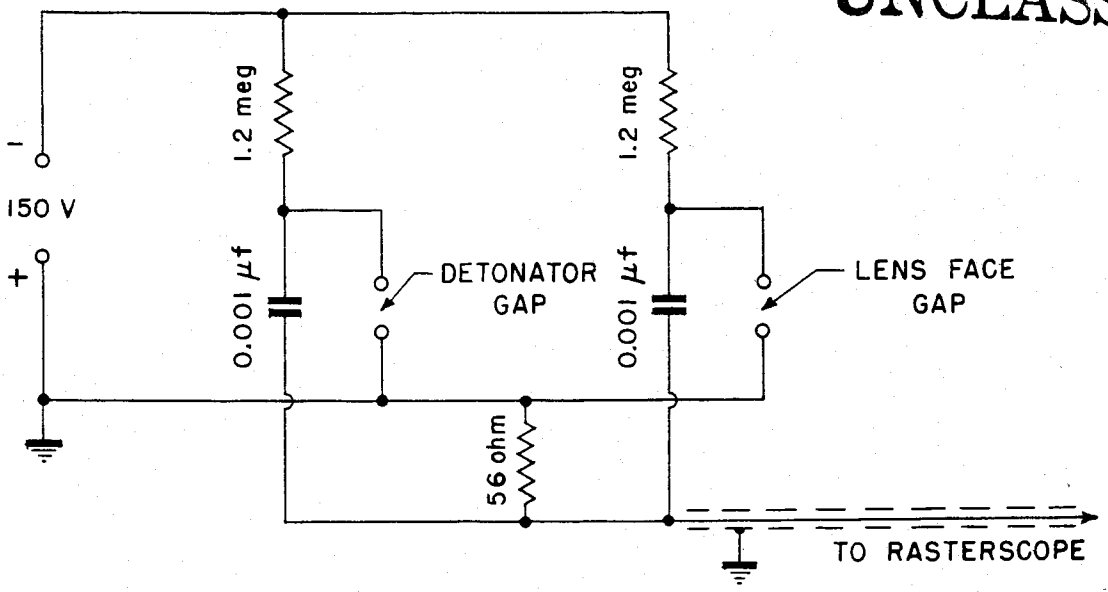


Fig. 4.18

fractional distance across the lens face as ordinates.

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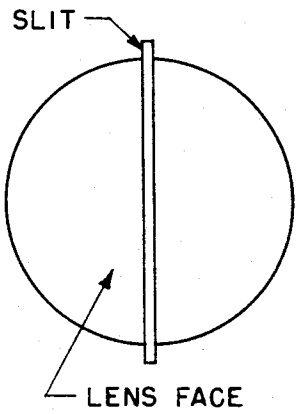


Fig. 4.19

In addition to testing lenses for simultaneity of emergence, the rotating-mirror, streak technique is of great value in the development of new lenses.

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One of the limitations of the procedure described above is that it permits of the examination of only a single strip across the lens face. Ideally, the whole area should be

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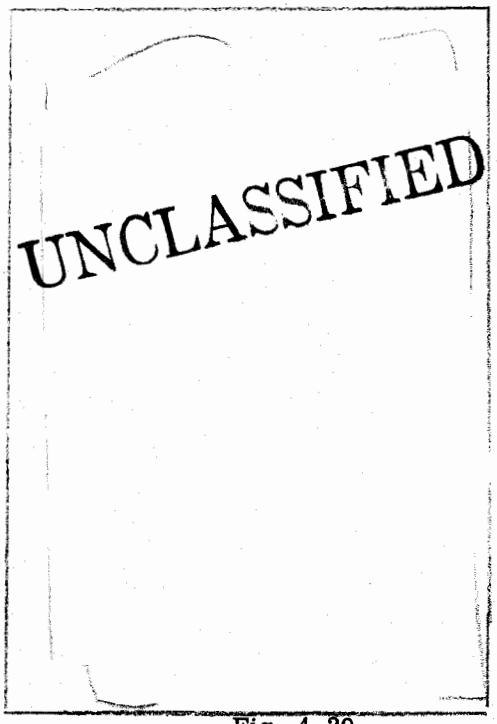


Fig. 4.20

studied, since the lens may not have axial symmetry. An approach to this ideal has been made by using a number of parallel slits, in place of a single slit, so that the whole face is essentially covered at the same time. However, the ordinary rotating mirror method cannot be used without modification because the various streaks would overlap.

[redacted] The b(

streaks obtained by the rotating mirror camera from several slits simultaneously are thus quite narrow and there is no overlap.

The technique involved in the multislit method is somewhat complicated, and so it is not generally used for lens testing. Its main application so far has been in an experimental study of the time spread, over a fairly large area, of the detonation wave as it leaves the lens and passes through various thicknesses of I.C.

Environmental Tests of Lenses and Inner Charges

As described in Section 4.2 for detonators, both lenses and inner charges are subjected to low (-90°F) and high (165°F) temperatures and also to temperature and humidity variations such as might be encountered under arctic, tropic, or desert conditions. Examination is made for significant changes in dimensions, for mechanical damage, e.g., stress cracks, and for the appearance of excessive exudation from the HE materials. Tests are being planned in which the HE system will be fired at both temperature extremes to determine the relationship between temperature and transit time.

Summary of HE Systems

For convenient reference, a summary of the characteristics of the HE systems in stockpile, in production, or which will soon be production, is given in Table 4.1.

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Table 4.1 Characteristics of HE Systems*

Outside HE diameter					
Lens Height					
	Comp B	Comp B	Cyclotol 75/25	Cyclotol 75/25	Comp B
Number of lenses					
Detonator	1E20	1E22	1E23	1E24	1E25
Transit times: Lens					

4.5 Implosion Performance Studies

The general behavior of implosion systems has been studied by three general methods. These are (a) the pin technique, (b) the RaLa method, and (c) photography. At the present time the pin technique is the most widely used for both testing and development work, whereas the RaLa and photographic procedures are now mainly employed in the study of special problems in development and research. A technique, employing radar, for the study of the detonation wave in the inner charge system is under development.

The Pin Method

In the pin method the times are recorded at which the implosion wave or material-air surface reaches various points within a sphere. One principle used is similar to that applied in the cable timing system for detonators (Section 4.2) and in the test firing of lenses (Section 4.4). The closing of a gap, at a known position, either by ionization due to the detonation wave or by actual metallic contact, causes a condenser to be discharged. This produces a deflection on an oscilloscope (or rasterscope) trace, which can be timed very accurately.

A simplified schematic diagram of the circuit is shown in Fig. 4.21. The gap, which is closed by ionization or contact, is at the top of the figure. One point of the gap is part of the

*While in the development stage, a weapon is given a TX number; when the final design has been released and approved for stockpile this is changed to a Mark number, which is usually, although not always, the same as the TX number. Code names, such as "Thor" and "Brok," used during development, are frequently retained.

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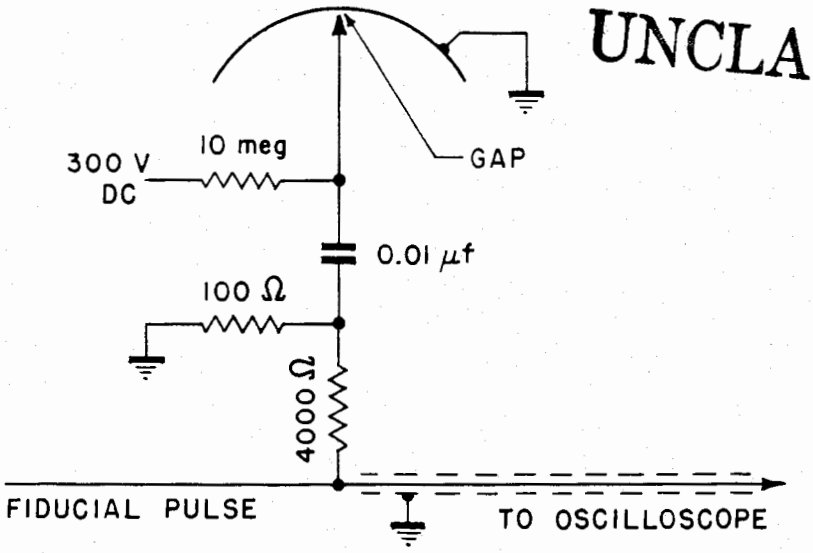


Fig. 4.21

implosion system being studied, whereas the other, indicated by the arrowhead, is a wire, often in the form of a long pin. It is from the appearance of these contactors that the name "pin method" originates. It may be mentioned that by using 300 volts to charge the condenser, no amplification of the oscilloscope pulse is necessary and consequently very rapid response is obtained.

Two main types of measurements are made by the pin method. These are called (i) tamper run, and (ii) ball run, respectively. The objective of the tamper run is to determine the transit time of the shock front through the aluminum pusher and the tuballoy tamper, the velocity of the inner (free) surface of the tamper through the air (free run) space in a levitated system, and the symmetry of the implosion wave, using a given HE system (Fig. 4.22). For this purpose, insulated contactors are located at the HE-pusher (A), pusher-tamper (B), and tamper-air (C) interfaces. In addition, a number of pins (D) of five or more different lengths are fixed into a so-called pin dome of an insulating plastic; this replaces the ball containing the fissile material in the actual bomb. Connection from each of these contactors or pins is made to oscilloscopes in the recording chamber which is protected from the explosion. In this way, the time arrival of the shock front at A, B, and C can be recorded, and the subsequent movement of the tamper-air surface can be followed down to very small radii, e.g., about 2 inches.

Although a relatively small number of pins are shown in the figure, the total number used may range from 100 to 300. If these are spread over an area, they provide a good indication

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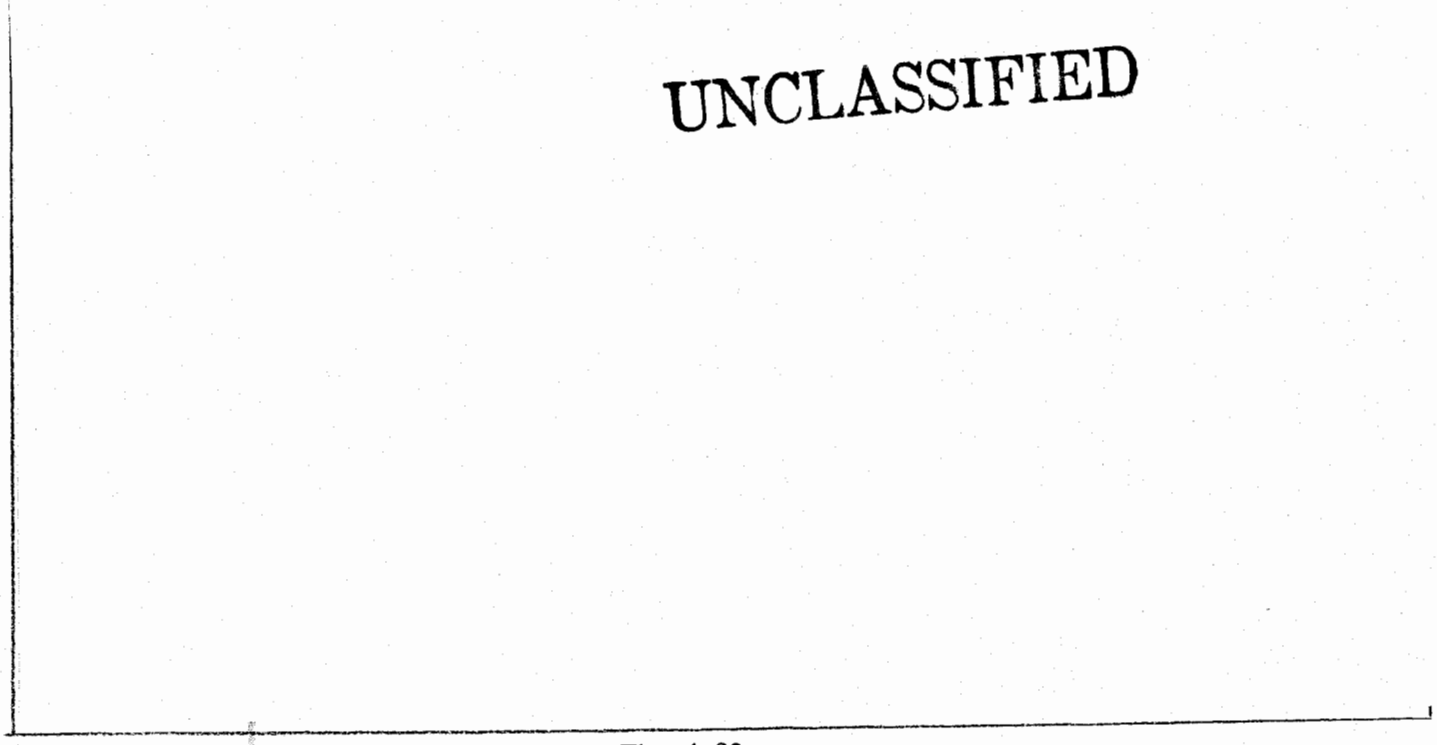
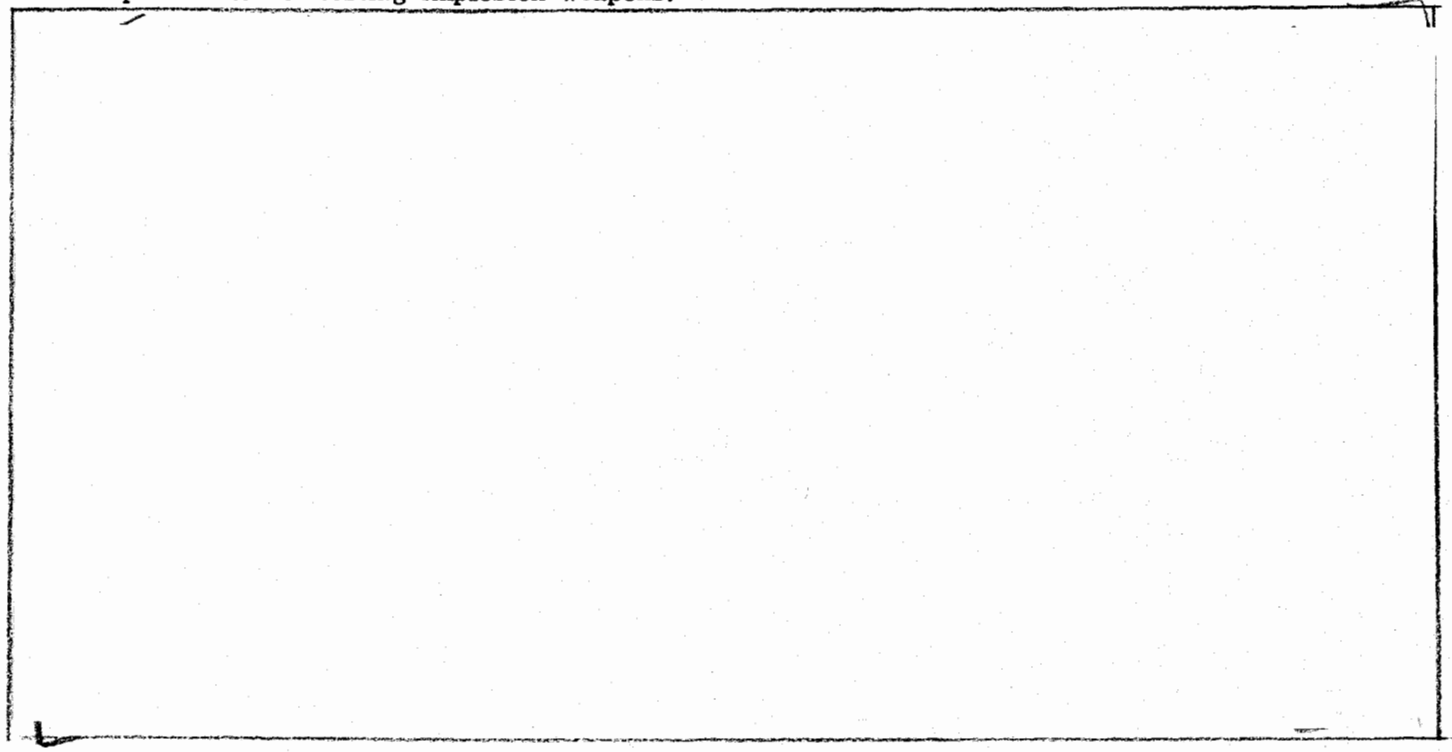


Fig. 4.22

of the symmetry of the implosion wave in that region. This is a highly important aspect of the pin method of testing implosion weapons.



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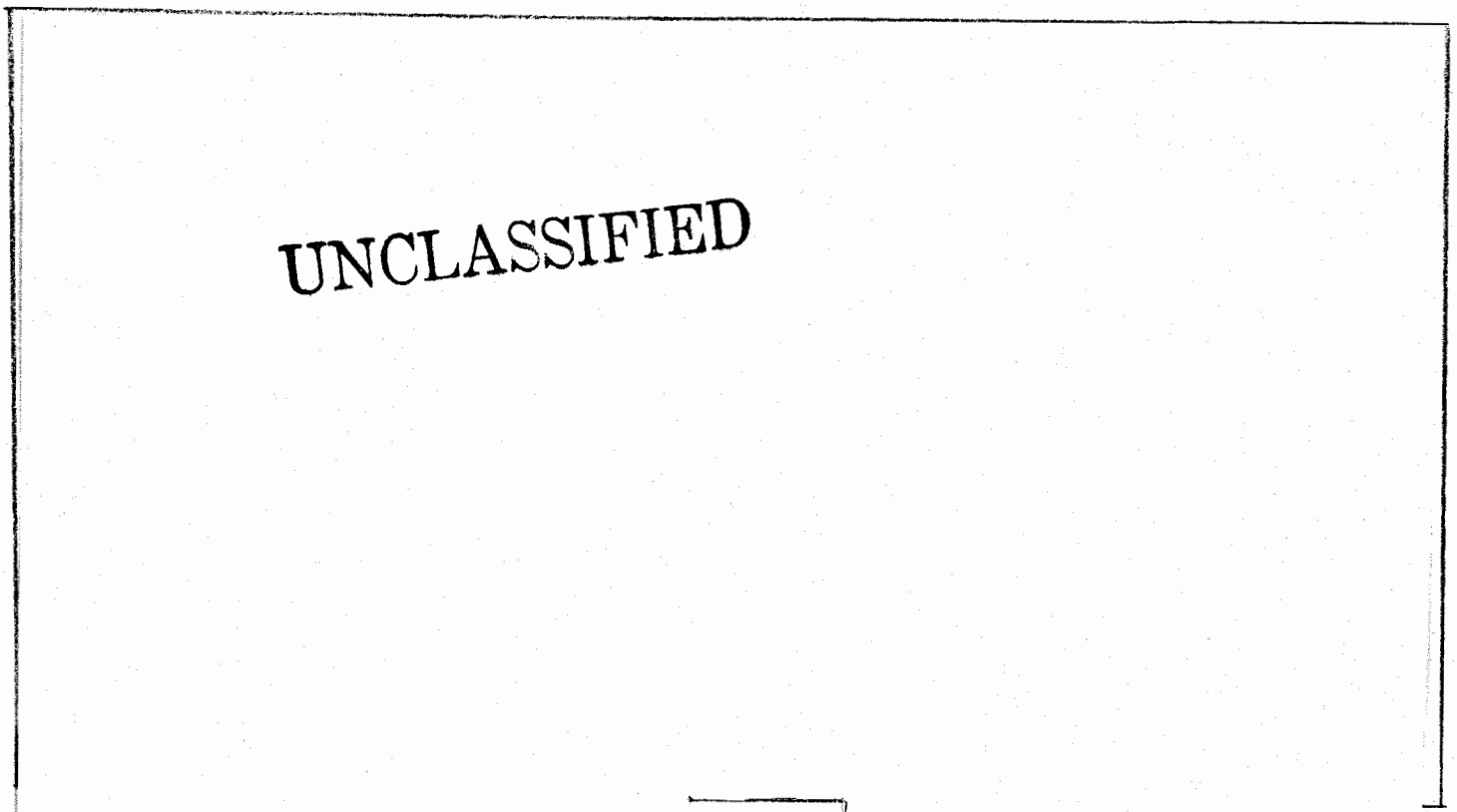


Fig. 4.23

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Asymmetry due to other causes can, of course, be studied in the same manner.

One purpose of the pin-method measurement described above is to check the actual free surface and shock velocities against those computed from hydrodynamic theory. From the transit time observations, ball time and collapse time, at which the shock wave reaches the outside of the ball and its center, respectively, can be determined.

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In addition, information is obtained concerning the effects of various factors on the symmetry of the implosion.

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For this purpose, shock and material velocities are determined. The data will be used to improve hydrodynamic calculations of the expected compressions and, hence, the yield of weapons of new design.

Because of its relative simplicity and adaptability, the pin technique is extensively used for implosion studies. Nevertheless, it has some drawbacks which may be mentioned. A portion of the spherical HE and tamper system must be removed to permit insertion of signal lead wires to the pins. This upsets the symmetry of the implosion near the opening.

As a result, measurements are reliable over a limited region of the sphere. Another fact which must be borne in mind is that a highly localized disturbance may reach a particular pin. In this case, the reading obtained could be misleading, but the use of a large number of pins minimizes the probability of this occurring.

The RaLa Method

The RaLa (pronounced "Rah-lah") method was originally used in connection with weapon design to indicate the compression of the ball as a function of time in an implosion and also to study the symmetry of the latter. Its main purpose at present, however, is to obtain data for verifying calculations based on equations of state at high pressures.

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The RaLa method of studying compression is based on the fact that the fraction of gamma rays absorbed (or transmitted) by the ball depends upon its compression. Consider a sphere in which the density (or compression) changes with time but remains uniform over the radius; then,

$$\text{Fraction of gamma rays transmitted} = e^{-\mu r}, \qquad (4.3)$$

where r is the radius of the sphere and μ is the mass absorption coefficient of the material for the given gamma rays.

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The oscillographs attached to the detectors give a record of the per cent transmission as a function of time (Fig. 4.24). From this the variation of compression of the ball with time can

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Fig. 4.24

be determined.

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By comparing the traces obtained from several detectors located around the implosion system, the symmetry of the wave can be investigated.

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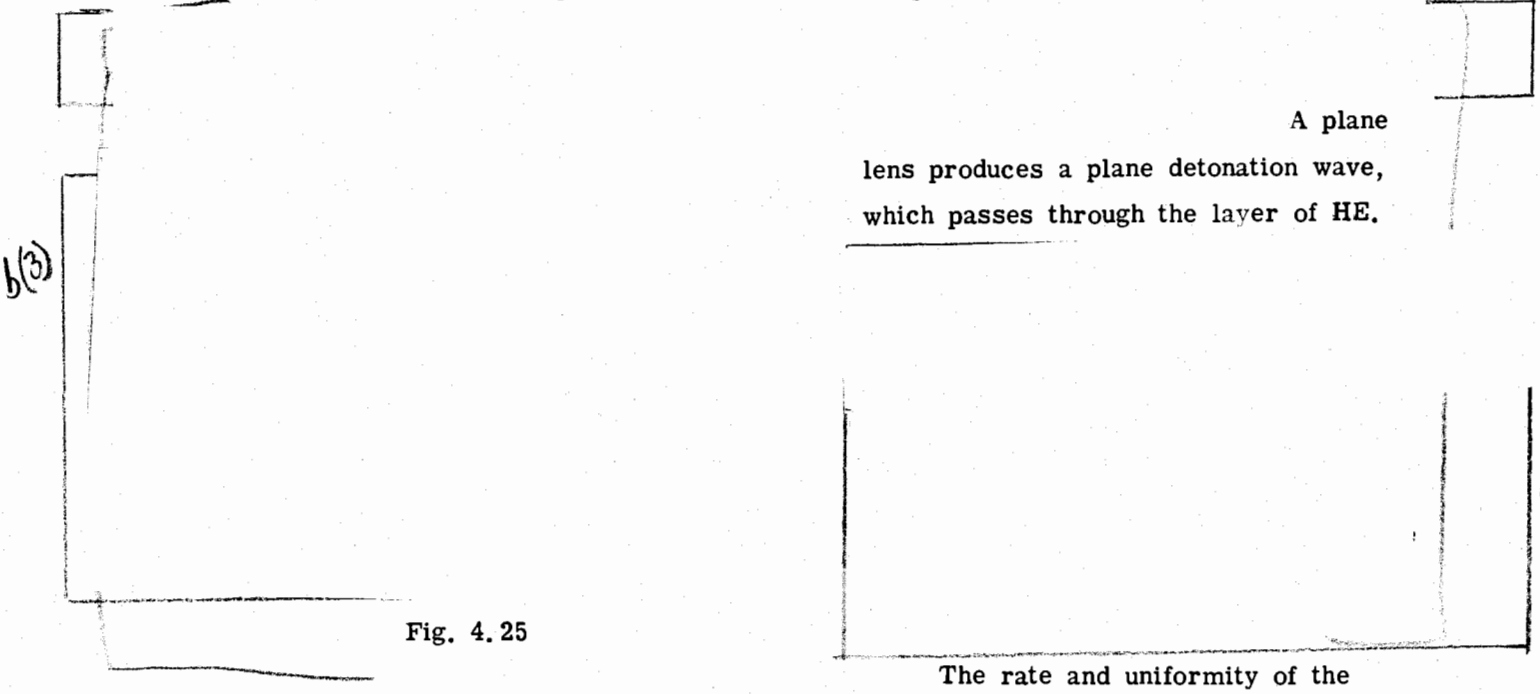
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Photographic Methods

In the study of implosion phenomena, photographic methods are chiefly applied to investigate the motion of metal surfaces, e.g., of the tamper or ball. In this way, the effects of perturbations in the detonation wave and in the shock wave, which may be due to the supporting structure for the ball, may be examined. Although the photographic technique is not generally employed for routine testing or design, it is used in trying out new ideas. For this purpose, a simple, rapid, and inexpensive procedure has been developed.

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A plane lens produces a plane detonation wave, which passes through the layer of HE.

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Fig. 4.25

The rate and uniformity of the movement of the free surface is studied by drawing a rectangular grid pattern on the lower surface of the plate.

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Advanced models of this rotating mirror camera have been designed which will take pictures at rates up to 3.5 million per second. The intense illumination of short duration required for these very brief exposures is obtained by passing a shock wave, produced by a detonation in HE, through a column of argon.

The plane lens and the HE used to produce the flash in argon are fired simultaneously, and a series of photographs of the grid, either perpendicularly or at a slant angle, are taken by the high-speed camera. From the pictures made at an angle it is possible to calculate the free surface velocity of the metal plate. In addition, from an examination of the grid, preferably in a direct view, qualitative information can be obtained concerning the symmetry of the shock wave. Results secured in this manner can be confirmed, if necessary, by means of a spherical implosion system with a grid drawn on a hemispherical surface.

In addition to the procedure just described, high-speed photography is used to produce profile shadowgraphs, i.e., edge-on views, of a plate subjected to the action of a shock wave. Information concerning departure from uniformity of motion can be detected in this manner.

On the whole, high-speed photography is best suited to qualitative studies; it is particularly valuable in providing a physical picture of the effects of a shock wave produced in a given manner. If more exact quantitative data are required the rotating-mirror streak camera, described in Section 4.2, is used to amplify the observations. The multiple slit procedure, referred to in Section 4.4, can provide quantitative information concerning leads and lags in the shock front at free surfaces. The photographs obtained with the high-speed framing camera facilitate the interpretation of the streaks.

High-speed, flash photography, like the other two methods of studying implosion effects, is used to derive equation of state data for metals at high pressures for theoretical calculations. In fact, this is the main application at the present time. Fortunately, the three procedures do not duplicate one another, as each is best suited to a particular range of pressures.

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The photographic technique is then particularly convenient, as described above.

Radar Technique

A proposal for the use of radar in the study of the rate of propagation of the detonation wave, and the effect upon it of convergence, in the inner charge system is under development. Due to the ionization it produces, the surface of a detonation wave is a good electrical conductor and so reflects radar waves, i.e., electromagnetic waves of short wave length, about 3 cm. Because the detonation front is in motion, the frequency of the reflected radar waves differs from that of the incident waves, as the result of a type of Doppler effect. From the beat frequency arising from the combination of incident and reflected waves, the velocity of the detonation front can be determined.

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Chapter 5

Components Design and Testing: The Nuclear System

5.1 Pit and Capsule Characteristics

Pit and Capsule Defined

The portion of an implosion bomb lying within the HE system consists essentially of two components: the pit and the capsule.

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Fig. 5.1

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If the final positioning of the capsule within the pit is performed while the weapon is airborne, the process is referred to as "in-flight insertion," abbreviated to IFI.

Characteristics of Pits

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Some of the important characteristics of the pits referred to above are summarized in Table 5.1.

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Table 5.1 Characteristics of Pits

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Characteristics of Capsule Balls

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For reasons connected with the limited life of the neutron (polonium-beryllium) source which initiates the fission chain, capsule balls must be disassembled from time to time and provisions for this must be made in their construction.

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The outer radii and compositions of the capsule balls are given in Table 5.2; the per cent plutonium indicates the proportion this element represents of the total fissile material.

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Table 5.2 Characteristics of Capsule Balls

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Fig. 5.2

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Fig. 5.3

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Fig. 5.4

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Fig. 5.5

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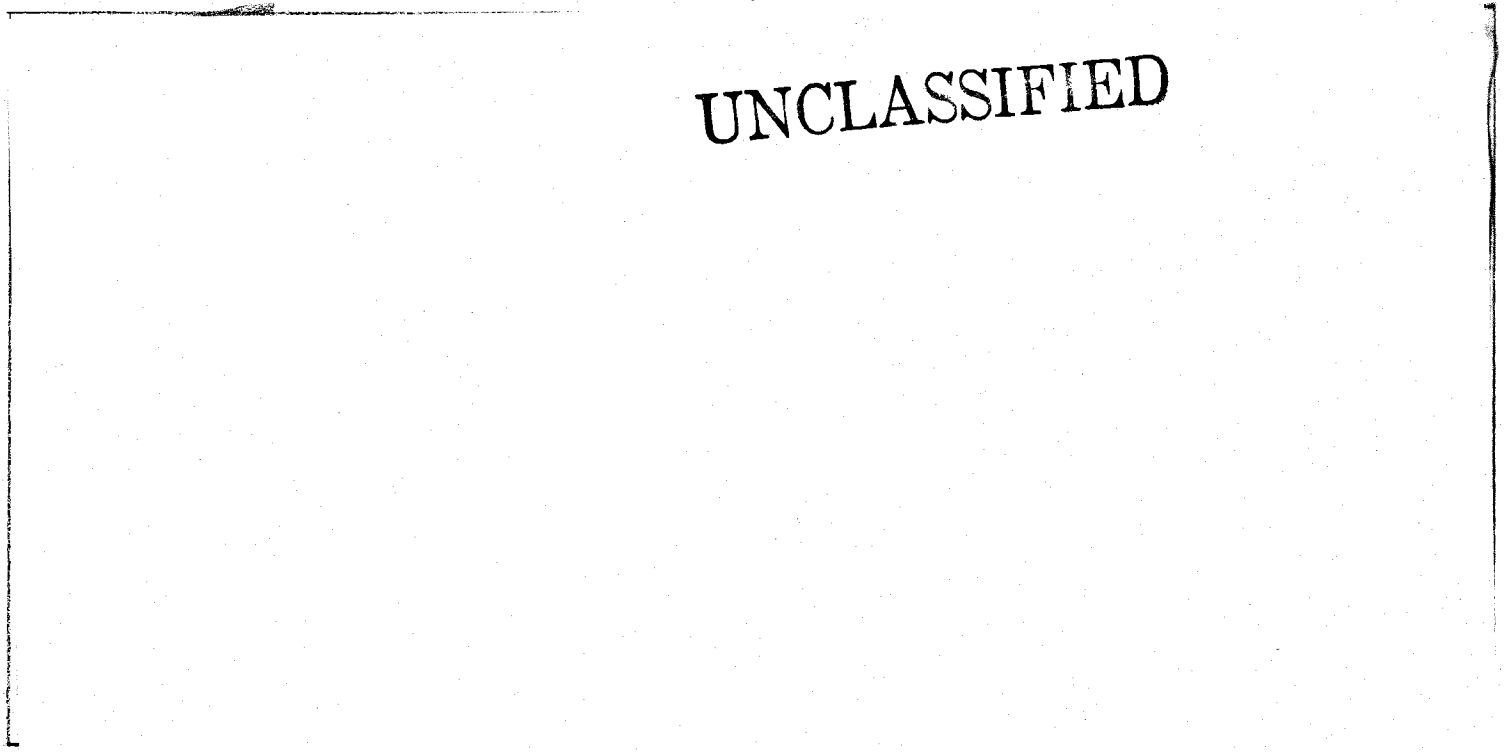


Fig. 5.6

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Fig. 5.7

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Table 5.3 Energy Yields in kilotons for Pit-Capsule Combinations

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5.2 Storage and Inspection Procedures

However, plutonium represents a very serious radiological hazard to personnel handling bomb capsules.

Capsules are therefore kept in steel carrying cases which are thoroughly dried by baking and then filled with dry air.

Safety in Storage

Safety during storage has two aspects, namely, personnel and nuclear. The main problem, as far as personnel are concerned, is the plutonium danger, referred to above. This is checked by what is called a swipe test. A piece of cleansing tissue is rubbed over the plutonium surface and then tested for alpha-particle activity by means of a suitable counter.

Although they do not represent such a serious radiological hazard as does plutonium, the swipe test is also applied to oralloy and tuballoy surfaces to determine if loose corrosion products have been formed.

Many steps are taken to insure nuclear safety. One of these, as already mentioned, is the separate storage of pits, with their HE assemblies, and capsules.

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A series of experiments on the neutron multiplication due to various numbers of cores spaced at certain regular intervals were made using remote control methods (see Section 5.7). As is to be expected, the over-all multiplication increases with the number of cores and with a decrease in their separation. However, provided the distance between adjacent cores exceeds a certain amount, a large number can be stored without the danger of the whole becoming critical. In actual storage practice, the minimum permissible distances between capsule cases are maintained by means of rigid partitions.

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Testing and Inspection (Surveillance) Procedures

All components of pits and capsules are subjected to rigorous testing and inspection, both at the time of manufacture, to insure that required specifications are met, and during storage, to detect possible deterioration. Although the detailed procedures vary according to circumstances, the following brief description of an acceptance inspection may be regarded as fairly typical; it is, however, merely an outline of the many operations which are performed

on the pit and capsule components and assemblies.

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In addition to visual inspection for obvious flaws, they are radiographed to detect possible internal faults.

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The ratio of gamma rays emitted to the total beta plus gamma radiation can be used as a qualitative indication of the isotopic composition of the uranium. The ratio is much less for oralloy than for tuballoy, so that the two materials may be readily distinguished. The actual amount of uranium-235 can be determined, if required for accountability purposes, by placing the core, or some portion of it, in a tamping geometry with a neutron source and observing the subcritical multiplication due to fission (see Section 5.7). Uranium-238 gives no multiplication under these conditions. The results are calibrated, in terms of the proportion of uranium-235 present, by mass spectrographic analysis.

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Periodic Inspections

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Other tests may be made as required by circumstances. The checking of the initiators, which is performed at the same time, will be described below.

Capsule and core parts which are stored in dry, pressurized air with silica gel as desiccant are normally inspected only at the time of initiator replacement. But capsules stored in unpressurized cases, also with silica gel, are inspected every 90 days. They are cleaned, if necessary, and the desiccant is renewed. No matter how it is stored, any capsule or component that has been exposed to temperatures below 0°F or in the range from 120° to 150°F for more than a week is inspected. A more detailed examination, involving disassembly, is necessary if the storage temperature has exceeded 150°F for any time or if the capsules have been accidentally subjected to violent handling, e.g., dropping.

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If the pit has been stored in a humid atmosphere, or under any conditions that might lead to condensation of water, inspection is necessary. This inspection usually involves a visual examination for corrosion blisters, pitting, and warping. The opportunity is then taken to clean the pit interior.

5.3 Fabrication of Pit and Capsule Components*

Plutonium Production and Fabrication

As extracted from spent reactor fuel elements (Section 1.5) by chemical processing, plutonium is almost invariably obtained in the form of a suspension or concentrate of the nitrate in water. In order to reduce the light element impurities, and thus decrease the neutron background due to (α, n) reactions, this is further purified. The nitrate is dissolved, in batches not exceeding 320 grams of plutonium, to avoid the possibility of the solution becoming critical, and hydrogen peroxide is added to precipitate plutonium peroxide. The peroxide is removed and heated to 550°C in a mixture of hydrogen fluoride gas and oxygen to form plutonium tetrafluoride (PuF_4).

The fluoride is mixed with calcium turnings, together with some iodine as a temperature booster, and heated to a starting temperature of about 400°C in a magnesium oxide crucible by means of an induction furnace. Plutonium turnings from fabrication processes may be added at this stage. The plutonium fluoride reacts with the calcium and is thereby reduced

*The following description applies to procedures used at Los Alamos; they are similar to those employed by other producers and fabricators.

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to plutonium metal; an argon atmosphere is maintained to prevent oxidation of the latter. Considerable heat is evolved in the chemical reactions which occur, and metallic plutonium, melting point 635°C when pure, drops to the bottom of the crucible and is removed as a button upon cooling. It is of interest to mention that all the foregoing processes are now performed by remote control.

Because the critical mass of plutonium is greater in the absence of water, it is permissible to operate with larger quantities in the dry stages. Thus, clean plutonium turnings or filings, obtained from metal fabrication processes, are added either to the fluorination or to the reduction stages for recovery. The metallic buttons obtained may weigh up to 750 grams.

During the reduction process gallium metal is added to form a plutonium-gallium alloy containing 1 per cent by weight of the latter element. The purpose of the gallium is to stabilize the plutonium in the delta-phase form.

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If the plutonium hemispheres pass the foregoing tests they are then examined radiographically and by autoradiography. The radiographic test, using gamma rays from cobalt-60, will detect the presence of cavities, cracks, etc. If these are in excess of a certain minimum size and number, the part is rejected.

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Oralloy Production and Fabrication

As stated in Chapter 1, oralloy, in the form of uranium hexafluoride, is obtained from the gaseous-diffusion plants. It is then of sufficient purity not to require further processing before reduction to metal, by the method given in Section 1.5. Nevertheless, the material is analyzed to make sure that the light-element impurities are not excessive. The metal, which does not have such good metallurgical properties as delta-phase plutonium, is fabricated by vacuum casting followed by machining to shape.

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After casting roughly into the required size and shape, the oralloy is machined to exact specifications. In the "as-cast" condition, the metal exists in the stable alpha phase, in which state its fabrication properties are not too good. From the relatively little work that has been done on uranium alloys, there is as yet no evidence that a form more amenable to fabrication can be stabilized at ordinary temperatures. Consequently, machining of castings is not the ideal method of fabrication and other procedures are being investigated (see below).

Additional problems arise in the fabrication of oralloy due to its chemical and radiological properties. Because of the rapid reaction with oxygen in the air, the chips, etc., produced are likely to ignite spontaneously. Small particles of metal will be oxidized and the resulting dust is an inhalation hazard. The operations are therefore carried out under hoods and the work is cooled to prevent ignition. Although oralloy is moderately radioactive, the manipulation of solid pieces is not especially dangerous, provided they are handled with protective gloves. The value of the material requires that great precautions must be taken to avoid losses of all kinds.

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After completion of the oralloy part it is radiographed to detect possible internal defects.

Tuballoy Production and Fabrication

Since the physical, chemical, and metallurgical properties of tuballoy are identical with those of oralloy, the procedures used for the production and fabrication are much the same. However, the handling of tuballoy is much simpler in many respects. In the first place, since there is no danger of criticality, larger masses can be melted and cast.

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The radiological hazard is appreciably less than for oralloy, and since it is less valuable, moderate fabrication losses can be tolerated.

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Because of the ease of oxidation, precautions against spontaneous ignition during machining must still be taken.

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Recovery of Plutonium and Oralloy

Because of their value as fissile materials, all residues of plutonium and oralloy are carefully collected for recovery. Plutonium in the form of metal, e.g., turnings, filings, etc., or of oxide, formed in casting, is dissolved in nitric acid with a little hydrofluoric acid. From the resulting nitrate solution (or slurry), plutonium peroxide is precipitated by hydrogen peroxide and sent to the plutonium production line. Magnesium oxide crucibles and molds and the calcium fluoride-iodide slag remaining from the metal reduction stage are dissolved in nitric acid containing aluminum nitrate. The plutonium is then recovered either by direct extraction in tributylphosphate (TBP) diluted with kerosene, or extraction after an intermediate stage involving volume reduction by precipitation of the plutonium with calcium oxalate as carrier. Organic matter such as clean-up paper, rags, etc., are first incinerated and the residual ash is then treated as just described.

Oralloy turnings and oxide residues are dissolved in nitric acid and after two stages of precipitation with hydrogen peroxide, to insure high purity, the resulting uranium peroxide is converted mainly to U_3O_8 by heat and is then reduced by hydrogen to the dioxide, UO_2. The action of hydrogen fluoride gas converts this to the tetrafluoride and the metal is finally obtained by heating with calcium. Magnesium oxide crucibles, slag, and other residues are treated in a manner similar to that used to recover plutonium. The materials are dissolved in nitric acid with aluminum nitrate and the uranium is extracted by means of TBP in kerosene.

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5.4 The Fission-Chain Initiator

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The Tom Initiator

The initiators in general use produce neutrons by the (α,n) reaction upon beryllium, with polonium as the source of the alpha particles (Section 1.5).

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Fig. 5.8

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Fig. 5.9

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Although the efficacy of the Tom initiator has been proven in several test explosions of complete bombs, a detailed study of some of its characteristics has been made.

Fig. 5.10

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*The maximum rate of neutron production is 2.8 neutrons/μsec per curie of polonium, for the (α, n) reaction with beryllium.

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Although the average rate of neutron production depends on the strength of the initiator, as expressed by the number of curies of polonium present, the actual emission is random in character, due to the nature of radioactive decay.

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Another important drawback of polonium-beryllium initiators arises from the fact that polonium is a very serious radiological hazard. A lethal dose is a millicurie, i.e., 0.001 curie, weighing only 0.2 μgram, i.e., 2×10^{-7} gram. Polonium metal oxidizes readily and the oxide easily escapes into the air. Consequently, very great precautions must be taken to prevent entry of polonium into the body, particularly by inhalation.

Testing Tom Initiators

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Two main checks are performed, both at the time of acceptance and

during storage. The purpose of the first is to determine the strength in curies so as to make sure it lies within the acceptable limits. This is done by measuring the intensity of the gamma rays by means of a Geiger, or other, counter.

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Fabrication of Tom Initiators

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Fig. 5.11

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5.5 External Initiators

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One problem in the use of an externally activated initiator is that of precise timing. For this purpose, it is necessary to know the transit time of the bomb, from the triggering of the X-unit to the time the implosion shock wave reaches the center of the core.

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The ENS Initiator

The new external initiator, called the ENS (Experimental Neutron Source), makes use of the fact that 14-Mev neutrons are released in the T-D reaction, between tritium and deuterium nuclei. However, the energy required to make the reaction take place is here supplied by accelerating tritium ions (tritons) in an electrical field; these high-energy ions then impinge upon, and react with, deuterium nuclei.

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Fig. 5.12

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The total weight of the present ENS and time-delay unit is just over 100 pounds and its volume is about 2 cu. ft.

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The neutron yield of the ENS initiator is more than sufficient to meet these requirements.

The reliability of the ENS system has been proved in numerous tests, although it has not yet been used in an actual weapon.*

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5.6 Details of Gun-Type Weapons

Introduction

As previously indicated, the gun-type bomb was the first nuclear fission weapon considered and was also the first to be used in combat.

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*A definite development program aimed at the design and production of an externally initiated implosion weapon has been started.

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Although the various components could be treated in turn, as with implosion weapons, it is more convenient, in the present case, to consider each gun-type weapon model as a whole.

Since the LB (Little Boy) bomb is now obsolete, it will be referred to very briefly.

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The length of the LB was 128 inches, including the 32-inch tail, and its diameter, with its ballistic envelope, was 28 inches; it weighed 8900 pounds, largely due to the very massive steel case.

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The Mark 8 Weapon

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This figure also indicates some of the more important dimensional characteristics of the warhead of the bomb.

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Fig. 5.13

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Fully loaded weapons can be safely stored side by side in any relative positions. In flight, safing is achieved by tapes on the arming mechanism, which interrupt the pyrotechnic chain; these are pulled out before the bomb is dropped.

The Abner Initiator

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The initiator designed for the Mark 8 weapon is called the Abner, shown in section in Fig. 5.14.

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close contact between the polonium and beryllium results in the occurrence of the (α, n) reaction and the emission of neutrons.

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After impact tests of the Mark 8, no significant change was observed in the neutron background of the Abner initiator.

Prior to assembling the parts of the Abner, the uniformity of the polonium coating is checked by means of autoradiography, using a pinhole camera. The alpha particles from the polonium produce a blackening of the film, after development. This is inspected visually for obvious flaws and by means of a microphotometer to determine the degree of uniformity of the polonium coating. The inspection tests after assembly are similar to those described for the Tom initiator, namely, gamma-ray intensity measurement, to determine the strength in curies, and a neutron background count. The Abner is also examined radiographically by means of X-rays, to make sure that it has been assembled correctly.

The Mark 9 Weapon

The Mark 9 weapon is an atomic artillery shell; it was designed to burst in the air at a prescribed time after launching from a 280-mm gun.

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The over-all length is

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54.8 inches, and the diameter is 11 inches at the base; the total weight is 805 pounds, and its maximum range is about 26,000 yards.

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The Mark 9 is said to be safe from the nuclear standpoint when immersed in or filled with water and in any position relative to another similar weapon.

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The temperature limits for storage are set at 110° to -40°F and 110° to -20°F for operation.

The Squab Initiator

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The initiator employed is called the Squab and two are used in each weapon for safety.

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Fig. 5.15

In addition to the counting and other inspection tests, the Squab units are radiographed, by means of X-rays. These tests are essentially the same as those applied to the Abner initiator, as described above.

The TX-11 Weapon

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In addition, it must be capable of external carriage by an aircraft at high speeds. These requirements are achieved by certain mechanical modifications which need not be considered here. The TX-11 bomb will also have an improved fuzing system.

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Fig. 5.16

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The Phoebe Initiator

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The general characteristics of the Phoebe initiator are shown in Fig. 5.17.

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The TX-19 Weapon

The primary requirement of the TX-19 is that it shall be an artillery shell, like the Mark 9, but weighing about 200 pounds less, so that its range may be increased by about 5000 yards.

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Table 5.5 Calculated Characteristics of TX-19 Shell with Various Tampers

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small difference in length is expected to have no significant effect on the energy yield. This

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Fabrication of Gun-Type Weapon Components

The fabrication procedures for the projectile, target, and initiator are much the same as those used for the components of implosion weapons. The oralloy is first cast in vacuum, and then machined to the proper size.

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5.7 Critical Assembly Measurements

Determination of Critical Mass

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However, these estimates must always be checked by critical measurements of the various partial or complete assemblies.

The approach to criticality is studied by determining the neutron multiplication in a number of subcritical assemblies. Although, by definition, a self-sustaining chain reaction is not possible in a subcritical system, there is nevertheless some neutron multiplication, as may be shown in the following manner. It was seen in Section 1.2 that if S neutrons are introduced into a fissile system, kS neutrons will be present after the first generation, k^2S after the

second generation, and so on. For a subcritical system k is less than unity, but for a just critical system k is unity. The total number of neutrons produced will then be the sum of S, kS, k^2S, etc., for all the generations.

If the system contained no fissile material, and there were no absorption, the injected neutrons would be unaffected, and the number present would be S. The ratio of the number of neutrons formed in the assembly containing fissile material to that in a similar system with no fissile material is called the neutron multiplication, M, and is given by

$$M = \frac{S + kS + k^2S + \cdots}{S} = \frac{1}{1 - k} \qquad (5.1)$$

Provided k is less than or equal to unity, so that the series is not divergent, the expression for M reduces to $1/(1 - k)$. For a subcritical system, i.e., $k < 1$, the value of M is finite and, in general, greater than unity. In other words, although a self-sustaining chain reaction is not possible, there is finite neutron multiplication before the chain dies out. For a critical system, k is unity, and the neutron multiplication, as given by equation (5.1), is then infinite.

For the determination of critical masses, it is more convenient to consider the reciprocal multiplication, i.e., 1/M, which, by equation (5.1), is given by

$$\frac{1}{M} = 1 - k \ . \qquad (5.2)$$

As long as the system is subcritical, 1/M is finite, i.e., it is greater than zero but less than one; when the system becomes critical, 1/M is zero. The neutron multiplication is observed for several subcritical systems containing different masses of fissile material and the observed values of 1/M are plotted against the masses. The extrapolated mass corresponding to $1/M = 0$ is then the critical mass under the given conditions.

The neutron multiplication is determined by placing a neutron source inside an assembly of active material of prescribed shape and of known mass, and measuring the rate of arrival of neutrons at a counter. The measurements are then repeated with the same source and counter using a similar assembly of inactive material, e.g., tuballoy. The ratio of the neutron counts in the two cases is proportional to the multiplication, M. Determinations of M are made for a number of assemblies of increasing mass, and then 1/M is plotted against the mass, as in Fig. 5.18. The extrapolated mass, for $1/M = 0$, is the critical mass. The apparent multiplication, as obtained in the foregoing manner, depends upon the position of the detector, but the 1/M values should always extrapolate to the same point, as indicated in the figure.

This procedure can be used to determine critical masses for both tamped (reflected)

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and untamped assemblies.

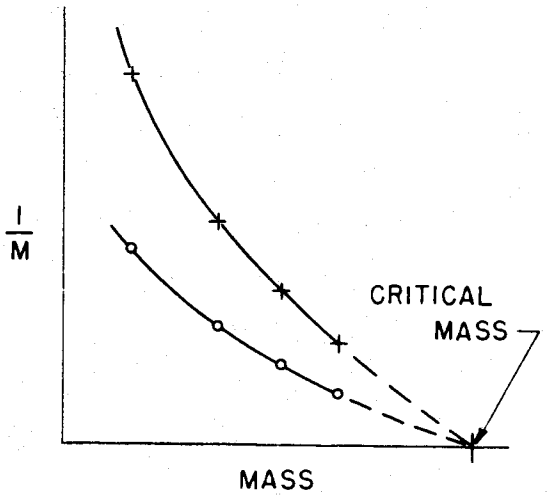


Fig. 5.18

[redacted] This number, required for efficiency estimates (Chapter 2), can be calculated from the available data.

Another aspect of critical experiments is to study safety measures to be used in the handling, fabrication, and storage of fissile materials. For example, the effect of water in causing criticality is investigated by means of paraffin, which has approximately the same neutron properties but is a solid. [redacted] Determinations are also made of the amounts of fissile material that can be safely melted, cast, or fabricated in various shapes.

The conditions for safe storage of weapons or weapon components are found by measuring what is called the cross multiplication. Suppose a number of cores (or weapons) are arranged at a certain distance apart, and the neutron multiplication in one of them, near the center of the array, is measured and found to be M_n. When all the other cores are removed, the multiplication in the same core is found to be M_1; then the cross multiplication, M_x, is defined by

$$M_x = \frac{M_n}{M_1} .$$

It is a measure of the effect on any one core of the surrounding cores. In order to be completely safe, the cores (or other components) should be separated by such a distance that the cross multiplication does not appreciably exceed unity. Then any one component is quite unaffected by the proximity of another one.

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Determination of Alpha

As a measure of the neutron properties of a multiplying system, measurements are made of the multiplication rate, α, in various materials. However, instead of determining the rate of increase of neutron density with time, the rate of decrease, after fission, is observed. The initial rate is dependent on the same α as determines the increase of neutron density. Two methods for estimating α have been used. In the first, less convenient, procedure, which has hitherto been employed in only one experiment, a burst of neutrons is injected by means of a betatron (see Section 5.5) into an assembly that is between delayed and prompt critical. A large number of chains are thus initiated, and the prompt neutron decay rate is determined by means of neutron counters. From this decay rate the value of the (prompt) α for the given system can be calculated.

The alternative (Rossi) method makes use of a near (delayed) critical assembly, a single neutron being introduced at intervals, either by spontaneous fission or from a suitable source. Each (effective) neutron starts a chain, which soon dies out; then another chain is started and dies out, and so on for the duration of the experiment. Thus, instead of being subjected to the neutrons from a large number of chains almost simultaneously the counters are exposed over an appreciable period to neutrons from a large number of chains one at a time. The method is thus statistical in character.

The neutron counting is carried out by means of a 10-channel delay circuit. The first channel is activated by an initiating pulse corresponding to the entry of a neutron; then, after a pre-determined interval, the second channel is activated for a short time; then, after another interval, the third channel is activated, and so on for intervals ranging from 0.25 μsec to a total of a few milliseconds after initiation. From the accumulated counts for the various channels, the time rate of decay of the prompt neutrons after fission can be calculated and α determined.

The value of α obtained in this manner, with near delayed critical assemblies, differs from that which applies to the highly supercritical systems in a fission weapon. By finding experimentally how α varies with the mass of material, it is possible, in principle, to estimate the multiplication rate for supercritical masses. However, such data have not yet been applied in theoretical efficiency and yield calculations.

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Chapter 6

Nuclear Weapons Tests

6.1 Purpose of Weapons Tests

Large-scale tests of assembled nuclear and thermonuclear devices are undertaken for many reasons. Some of these are: to proof-test a weapon or warhead before it enters the stockpile, as a check on the engineering, fabrication, and integration of the components into an effective whole; to test new designs of weapons and components before undertaking their fabrication; to test new principles and ideas which show promise for weapon developments; to provide information required to confirm or correct theoretical calculations and to enable further work to proceed, etc. The reasons may perhaps be summarized in the statement that the purpose of weapons tests is to check the efficacy of new designs of both components and assembled devices and to supply information that is essential for long-range improvements.

Although many basic data can be obtained in the laboratory and by calculation, there are numerous aspects of development work which require full-scale tests. [redacted]

[redacted] In addition, advances in the thermonuclear field are very largely dependent upon information that can be obtained in no way other than from an actual nuclear explosion. Such tests also provide opportunities for the development of new measurement techniques or for improving existing ones. Consequently, the testing of weapons and related devices is an important and continuing function, without which little progress could be made in weapons design and development.

Weapons test are sometimes performed for the purpose, direct or incidental, of studying the effects of atomic explosions on structures and materiel. Such information is required mainly for military planning and for civilian defense.

6.2 Atomic Proving Grounds

Introduction

The first test explosion of a nuclear weapon was made at Alamogordo, New Mexico (Trinity, 1945), and the next such operation (Crossroads, 1946), whose main purpose was to investigate the effect of atomic explosions on ships and their equipment, was carried out at Bikini in the Pacific Ocean. When it was decided, in the interest of safety, that no tests of nuclear weapons should be made within the continental limits of the United States, the Pacific Proving Grounds were established at Eniwetok Atoll. They were first used for Operation Sandstone in the Spring of 1948, and subsequently for Operations Greenhouse (Spring, 1951) and Ivy (Fall, 1952). The Castle tests (Spring, 1954) will also be conducted in the Pacific.

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Because of the difficulties and delays associated with operations at a remote location, and because certain information was needed urgently for Operation Greenhouse, the decision not to test nuclear weapons within the continental United States was later rescinded, and the Nevada Proving Grounds were developed. The first tests (Operation Ranger) were made there during the early part of 1951. Since that time, tests involving devices of relatively low energy release have been performed, as far as possible, in Nevada, whereas devices for which large yields are expected are tested at the Pacific Proving Grounds. The operations carried out at Nevada, after Ranger, were Buster-Jangle (Fall, 1951), Tumbler-Snapper (Spring, 1952), and Upshot-Knothole (Spring, 1953).

Nevada Proving Grounds

The Nevada Proving Grounds are rectangular in shape, measuring 40 miles from north to south and 16 miles from east to west, located in southern Nevada. Within this area are two alluvial valleys or "flats," namely, Frenchman Flat and Yucca Flat (Fig. 6.1), with moderately level surfaces of loose dust and gravel. It is in these flats that the target areas are located; these areas can be used for tower shots, i.e., for devices which are detonated at the tops of towers, generally 300 ft. high, or for air bursts, i.e., weapons dropped from aircraft or shot from a gun. Areas F, in Frenchman Flat, and 9 and 10 have been used for weapons effects shots, as well as for development tests.

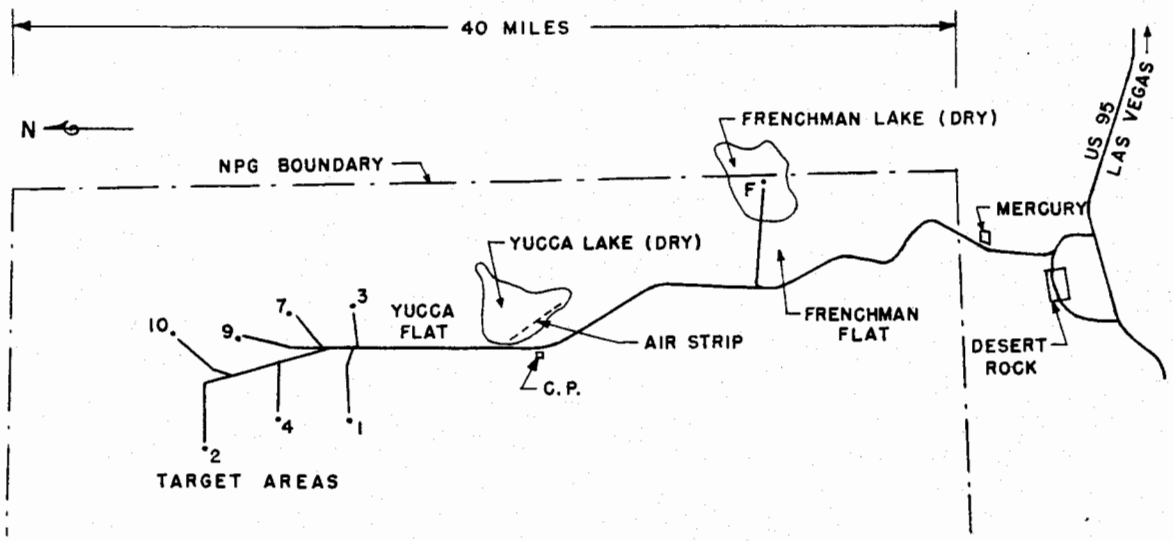


Fig. 6.1

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The Control Point (C.P.) area is located between Frenchman and Yucca Flats near the Yucca (dry) Lake. Here are a number of structures, including the control building where timing and firing signals originate. This building also houses the office of the test director and his staff, the weather service, and various scientific, electronic, and machine shop facilities. The Rad-Safe section, which is responsible for radiological safety operations, including personnel monitoring and decontamination, occupies another building in the C.P. area.

Associated with each of the target areas are a number of concrete shelters, usually underground and covered with protective mounds, for various instruments required to study the phenomena accompanying the nuclear explosions. These shelters are built to withstand shock and to protect the instruments from damage and film from radiation exposure; hence, they are of a relatively permanent character. The distance of the instrument shelter from the zero point is determined by the needs of the particular measurement to be made; it usually represents a compromise between the increased cost of long cables if the distance is large and of the heavier structure required if the distance is short. The instrument shelters are provided with power supply, cables to the target area zero point, timing signals, and various other facilities. Most of the equipment is activated by remote control, utilizing relays energized by signals from the central timing system.

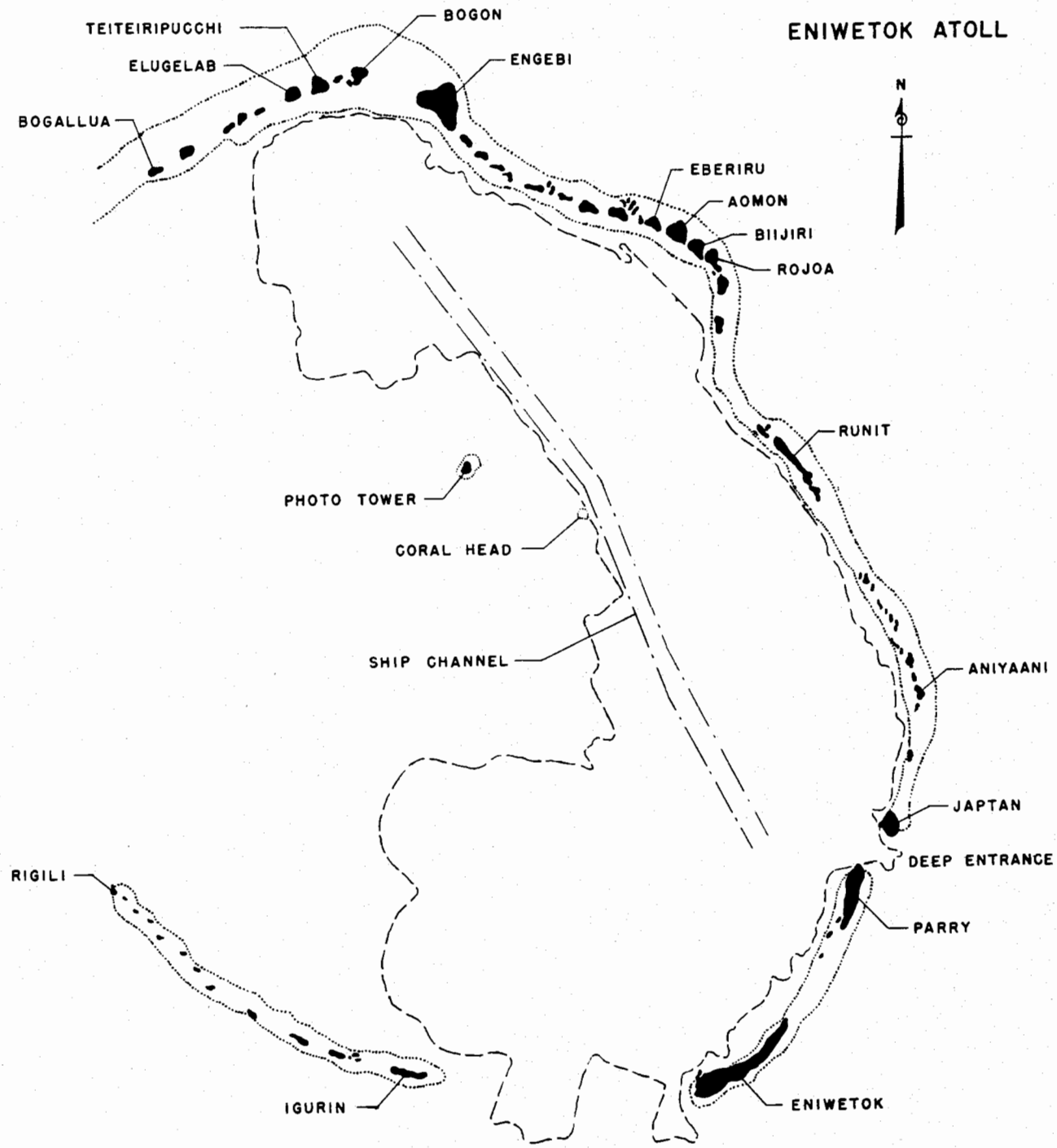
The local headquarters for several organizations connected with NPG activities are at Mercury, Nevada, just outside the southern boundary of the Proving Grounds proper. Various administrative offices are located there, and offices and laboratory facilities are available for experimental groups in some thirty quonset huts. Living quarters are provided at Mercury for civilian and military personnel engaged in the test operations. Military personnel receiving tactical orientation are quartered at Camp Desert Rock, about three miles southwest of Mercury.

Pacific Proving Grounds

The Pacific Proving Grounds include the Eniwetok (Fig. 6.2) and Bikini Atolls (Fig. 6.3); although the latter has not been used since Operation Crossroads in 1946, new facilities are being installed for the Castle tests in 1954. The two atolls are about 180 miles apart, and communication between them is maintained by air, sea, telephone, and radio. These atolls, which are from 13 to 25 miles across, consist of more or less circular groups of small coral islands, covered to varying depths with coral sand. As a general rule, the individual islets are connected by a coral reef, although much of this may be submerged even at low tide. There are, however, gaps in the reef through which ships may enter the lagoon.

The test operations at the Pacific Proving Grounds are performed by a task force composed of scientific and military personnel whose headquarters are located on Parry Island or aboard ship. Living accommodation is provided on Eniwetok and Parry Islands, although during

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Fig. 6.2

BIKINI ATOLL
N
BIKINI
ENYU
ROMURIKKU
AOMOEN
UORIKKU
YUROCHI
AIRUKIIJI
AIRUKIRARU
BIGIREN
REERE
ENINMAN
ENIIRIKKU
NAMU
BOKOBYAADAA
DELTA
CHIEERETE
RUKOJI

Fig. 6.3

an operation some personnel may spend most of their time in temporary camps on other islands where tests are being made.

Different islands are selected as target areas, according to circumstances. For example, Engebi, Aomon, and Runit were used for Sandstone; Engebi, Eberiru, and Runit for Greenhouse; and Elugelab and Runit for Ivy. In Castle it is planned to detonate some test devices over water in the lagoon. Instruments are located in shelters, similar to those at NPG; these may be on the target island itself or on an adjacent island. In addition, photo-towers for cameras are spread throughout the atoll. At Eniwetok the timing and firing signals originate from Parry Island, and at Bikini from Enyu Island. The signals are transmitted by cable or by radio according to circumstances, partly determined by distance and the importance of the experiments.

Because of the climatic and other conditions at the Pacific Proving Grounds, instrument shelters are primarily designed for use in a single test. Nevertheless, they may serve for several tests if they are in operative condition. In general, the facilities available are similar to those outlined above for the Nevada Proving Grounds.

6.3 Nuclear Explosion Phenomena

The Ball of Fire

In order to understand the significance of some of the measurements made in the course of weapons tests, it is desirable to review briefly certain phenomena associated with a nuclear explosion. After the initial stages of radiation flow and its cessation, when the temperatures are much higher, the bomb material will be at a more or less uniform temperature of about $1,000,000^{\circ}K$, i.e., 0.08 kev. In this condition there is a considerable emission of energy as electromagnetic radiations covering a wide range of wave lengths, from infrared (thermal) or longer, through the visible to the ultraviolet and beyond. Much of this radiation is absorbed by the air immediately surrounding the bomb, with the result that the air itself becomes heated to incandescence. In this condition, the detonated bomb begins to appear, after a few microseconds, as a luminous ball of fire.

As the ball of fire grows, and its temperature falls to about $300,000^{\circ}K$, at about 0.1 to 1 millisec after detonation, a shock wave develops. At first, the shock front coincides with the radiation front, but as the temperature falls, the (luminous) shock wave moves ahead of the radiation. The reasons why the shock front travels more rapidly than radiation under these conditions is somewhat as follows:

In a vacuum radiation photons travel with the speed of light, but as the high energy photons move forward into the air, they are likely to be captured by the molecules (or atoms) present. The resulting excited molecules (or atoms) retain their excess energy for a time and

then emit it as another photon of the same, or slightly different, energy. If the mean free path, i.e., the distance between successive captures, of a high-energy photon is taken to be 0.01 cm, and the life of the excited molecule is 10^{-8} sec, then the effective speed of the photon is about 10^6 cm per sec. But since the emitted photon moves off in a random direction, the rate of forward motion, i.e., in the direction the radiation is propagated, will be considerably less. In fact, it will be less than the velocity of the shock front at the high temperatures and pressures existing in the ball of fire.

Since the shock front is luminous, the diameter of the ball of fire, as seen by the (protected) eye or by a camera, is determined by the motion of the shock wave. The lagging radiation front is not seen because of the high luminosity of the surface of the ball of fire. As the shock wave expands, the ball of fire is observed to grow rapidly in size for about 20 to 100, or so, millisec, depending on the yield of the bomb. At the same time, the surface temperature continues to fall, and when it reaches about 2000°K, the shock front is no longer luminous.*

From roughly this point on, the apparent size of the ball of fire is determined by the radiation front which may now be visible, or by air heated by shock passage. The rate of increase of diameter with time is less than before, since the radiation front still advances more slowly than the shock front. Hence, the invisible shock front continues to travel ahead rapidly; after 1 sec it may be some 600 yards beyond the ball of fire and after 10 sec it may have advanced two miles or more.

The point at which the (invisible) shock front moves ahead of the (visible) ball of fire is call the "breakaway." As stated above, the surface temperature of the ball of fire is then about 2000°K. However, the temperature of the radiation front is considerably higher, and as this begins to replace the rapidly cooling and advancing shock front, the surface temperature of the ball of fire apparently increases once again. This effect may be enhanced by a decrease in the opacity of the air. The apparent surface temperature thus rises until the temperature of the hot core, i.e., about 7000°K, is attained, and it then falls steadily due to cooling of the gases by radiation and by expansion.

The variation of the surface temperature (T) of the ball of fire and its apparent radius (R) after the nuclear explosion, is indicated in Fig. 6.4, in which both scales are logarithmic. The breakaway point corresponds to the first minimum in the temperature curve, after which the surface temperature rises, as stated above. It is seen, from the marked change in direction of the R curve, that the ball of fire grows at a much less rapid rate after the breakaway point. The luminosity (or radiation flux per unit area) of the ball of fire depends on the

*Times and temperatures given in this and the succeeding paragraphs vary with the yield of the weapon. They are particularly applicable, however, to weapons with yields in the range from about 10 to 100 kt.

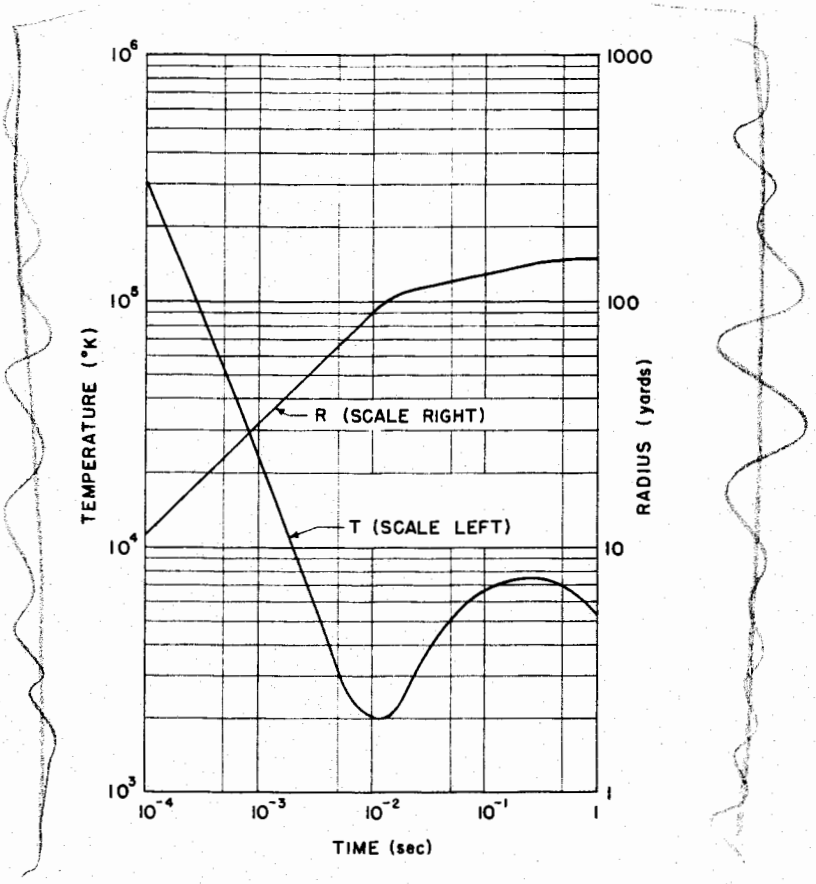


Fig. 6.4

surface temperature, being roughly proportional to T^4, at a given distance. It follows, therefore, that after the explosion the luminosity will first decrease to a minimum at the breakaway, increase to a maximum, and then gradually fall off to zero in the course of time.

It may be mentioned that various oxides of nitrogen are formed in the air surrounding the ball of fire and they have some influence on its luminosity. Above 5000°K these oxides are almost completely dissociated into atoms, but below this temperature some nitrogen dioxide, which is a brown gas, is formed. This undoubtedly contributes to the decrease in luminosity just before the breakaway. Molecules of gaseous nitrous acid have a similar effect.

At least for as long as the ball of fire is visible, it emits what is generally called prompt or effective thermal radiation, although it covers a considerable range of wave lengths. After traveling an appreciable distance in air, however, almost all radiations of wave lengths less about 3000 Å are absorbed. The proportion of the bomb energy liberated in the form of effective or prompt thermal radiation varies with the yield, as will be seen later.

Atomic Cloud and Fall-out

When the ball of fire has cooled appreciably, the vapors of fission products and other bomb residues condense to form a smoke made up of small solid particles having a range of sizes. This, together with any dirt or sand that may have been sucked up from the earth's surface, ultimately forms the atomic cloud. The rate of ascent of the cloud column depends upon the metorological conditions. At first it climbs rapidly, reaching an altitude of 10,000 ft in less than a minute, but later it slows down, so that the maximum height, of about 40,000 to 60,000 feet, may be attained in 10 minutes or so. The actual times and heights are determined by the energy release of the bomb as well as by the atmospheric conditions, but the values quoted may be taken as more or less typical.

Upon entering a region where the density of the atomic cloud is the same as that of the surrounding air, e.g., when the base of the stratosphere is reached, where the temperature of the atmosphere is almost constant and there is practically no motion due to convection, the cloud will spread out for a distance of several miles and form the characteristic mushroom shape. This is ultimately dispersed by winds into the surrounding atmosphere. If, in its ascent, the atomic cloud column should pass through a temperature inversion layer, it will tend to "mushroom" out horizontally to a small extent, but the main movement will still be upward, until the conditions are suitable for the extensive spreading just described.

When the cloud particles, which consist chiefly of highly radioactive oxides of fission products, uranium, etc., collide with particles of dirt they generally adhere. The resulting radioactive particles gradually fall back to earth, giving rise to the phenomenon known as "fall-out." The extent and nature of the fall-out depend on various circumstances associated with the height at which the nuclear device was detonated, the nature of the terrain, and the meteorological conditions. The importance of the fall-out lies in the fact that it may constitute a radiological hazard.

Gamma Radiation

Although gamma-ray emission accompanies the actual fission process, it is probable that this particular radiation is largely absorbed in the heavy bomb material, so that only a very small proportion escapes. However, within a very short time, usually a fraction of a microsecond, depending on the bomb model, gamma rays are produced by indirect or secondary processes. The two most important are due to the neutrons liberated in fission. First, there are the (n,γ) or radiative capture reactions, in which neutrons are captured by nuclei present in the bomb residues, followed by the emission of gamma rays. In addition, inelastic scattering of fast fission neutrons by heavy, e.g., uranium, nuclei also results in the production of high-energy gamma radiation. It is these secondary radiations which constitute at least the whole of what is called the "prompt" gamma rays associated with a nuclear explo-

The gamma rays liberated after the first few microseconds are referred to as "delayed" gamma rays. These radiations may be divided into two categories. Up to about 0.3 sec after the explosion, the delayed gamma rays are due mainly to (n,γ) captures by nitrogen of the air. The gamma rays produced in this manner have high energies, chiefly in the range from 5 to 8 Mev; at distances greater than 2,000 yards from the explosion they may make the major contribution to the gamma radiation received from a fission weapon.

The second category of delayed gamma rays is made up of radiations of lower energy (2 to 3 Mev) emitted in the radioactive decay of the fission products, especially those of short life, present in the ball of fire and in the atomic cloud. Although the delayed gamma radiation is actually formed, with decreasing intensity, over a long period of time, it is generally assumed, for practical purposes, that the emission lasts for a minute or so. In the first place, the fission products of very short life, which make the major contribution to the gamma radiation immediately after the explosion, will have decayed almost completely in this time. Further, by the end of a minute, or less, the radioactive cloud will have attained a height of some 2 miles, as indicated above, so that the delayed gamma radiation is attenuated to negligible proportions before it reaches the ground. The transmission of gamma radiation from the fission products is strongly affected by the hydrodynamics of the shock wave which removes a large proportion of the air between the bomb and detecting instruments on the ground.

Emission of Neutrons

The great majority of the neutrons liberated in a nuclear explosion are the prompt neutrons emitted simultaneously (or almost simultaneously) with the fission process itself. There are, in addition, the delayed neutrons, constituting less than 1 per cent of the total (Section 1.2), but these are of little significance in the present connection. However, even though the neutrons which succeed in leaving the detonated bomb originate as prompt neutrons, there is some delay in reaching the earth's surface.

It was seen above that some of the fission neutrons are captured in the bomb material and others undergo inelastic collisions and thereby have their energy decreased, i.e., they are slowed down. A few fast neutrons succeed in escaping, but the others are slowed down to some extent by elastic collisions with the light elements present in the HE system. The (relatively) slow neutrons are temporarily trapped here, but as the shock wave moves outward from the core, the material is dispersed and the neutrons escape into the surrounding air. The transport of the slow neutrons through space is thus strongly affected by the shock wave. In their diffusion through the atmosphere, some of the neutrons are slowed down still further and may then be captured by nitrogen nuclei.

Because of the various possible scattering processes which they may undergo, the neutrons

reaching a detecting instrument on the ground will cover a large range of energies. The distribution of the neutrons in this manner is referred to as the neutron spectrum. Those neutrons which have not been scattered have high energies, e.g., 3 Mev or more; others have energies in the intermediate range, while the great majority are slow neutrons. However, because of capture by nitrogen nuclei, very few have energies below about 0.2 ev.

b(3)

The proportion of neutrons produced in fission with energies as high as 14 Mev is very small, but if the D-T reaction is involved, a considerable number of neutrons of this energy will be detected.

6.4 Diagnostic Tests

Determination of Transit Time

A very great variety of measurements are usually made for each test shot, many of which depend upon the particular information required. However, for essentially all fission weapons the so-called standard diagnostic tests are made; these are the determination of the over-all transit time, the multiplication rate (α), and the energy yield of the device. Although yield measurements are always made, determinations of transit time and α are sometimes omitted. Apart from providing useful practical information, the results of the diagnostic tests serve to check theoretical estimates and to supply data upon which further calculations may be based.

For the measurement of the over-all transit time, i.e., from the instant of firing the detonators to the explosion time, two general methods have been used. In the case of a tower shot, a signal is sent over a coaxial cable to a distant cathode ray oscilloscope when the X-unit is fired. The first gamma rays to appear outside the bomb are picked up by a scintillation detector and a second signal is transmitted by cable to the oscilloscope. After making allowance for the difference in lengths of the cables and the time taken for the gamma rays to reach the detector, the transit time of the bomb can be determined from the separation of the two signals.

The procedure described above, which requires cable connections to the X-unit, cannot be used for an airdrop, and in this event the remote method is employed. A radio transmitter, operating at low power, e.g., about 20 watts, is attached to the bomb case. When the X-unit is fired, the output is instantaneously raised to several hundred watts, so that the signal can be detected at a distance and recorded on an oscilloscope. This continues until the intense ionization of the atmosphere, referred to as the "ion curtain," in the vicinity of the bomb, due to the gamma radiation, prevents further propagation of the radio signal. The level at which

this transmission is cut off is not known exactly, but it is believed to be at about the 30th generation, or so. Allowance for this delay is made in estimating the transit time from the duration of the radio signal. If the generation time is relatively long, e.g., for low values of α (Section 1.4), this correction may involve an appreciable error.

Determination of Alpha

Until recently, only one satisfactory method was available for determining the multiplication rate, α; it was based on a measurement of the time-dependence of the prompt gamma rays over a period of about 1 μsec. It can be seen from equation (1.16) that α can be determined if the neutron density, n, in the exploding bomb is known as a function of time. As seen above, the prompt gamma rays are produced, almost entirely, by the action of neutrons within the bomb. Hence, the prompt gamma-ray intensity, fairly close to the bomb, may be taken as being proportional to the neutron density. Consequently, α can be readily calculated from the variation of the prompt gamma rays with time.

Originally large (Rossi-type) ion-chambers, having a fast response, were used to detect the gamma rays, but these have now been replaced by scintillation detectors. The latter are located near the bomb, in the case of a tower shot, and long coaxial cables connect them to the horizontal plates of an oscilloscope. A constant, high-frequency sinusoidal signal applied to the vertical plate supplies a timing record. The oscilloscope trace is photographed and then analyzed to give the time dependence of the prompt gamma-ray intensity. By the use of additional cable, the gamma-ray signal is delayed, so that an intensifier pulse to the oscilloscope can build up and thus permit the trace to be photographed.

In order to cover the large range of intensity, several scintillation detectors may be placed at various distances from the bomb. A common timing system is sometimes used for all the oscilloscopes to which they are connected. The detectors nearest to the explosion record the lower intensities of gamma radiation, whereas those which are more remote indicate the higher intensities. Proper allowance is made, of course, for the attenuation with distance.

For an airdrop the scintillation detectors cannot be placed near the bomb. Consequently, they are located on the ground at known distances from the assumed detonation point. Because of the absorption of the radiation, the intensities at the detectors are relatively small and for high bursts amplifiers may have to be used.

b(3)

Another procedure for obtaining α, which avoids destruction of the detectors, etc., and can be used either for tower shots or airdrops, was first tried out at Operation Sandstone, but did not reach a satisfactory state of development until the Upshot-Knothole test in 1953. One

of its great advantages is that measurements can be made at a distance of 10 miles or so, where the instruments are under direct control, and no coaxial cables are necessary.

When the prompt gamma rays are degraded in energy and absorbed by the air around the bomb, they produce a luminosity, called the Teller light. The intensity of this light is proportional to that of the prompt gamma rays and, consequently, to the neutron density.

b(3)

[redacted] It is essential that the only light measured should be that coming directly from the bomb to the observer.

In one arrangement for recording the luminosity at very low levels, without the necessity of amplification of signals, the Teller light from the bomb is reflected by a mirror system (Fig. 6.5) and falls on the photomultiplier tube. This is placed as close as possible to the deflecting plates of a cathode-ray oscilloscope tube in a light-tight box. The timing and delay circuits are analogous to those used in the method already described. To provide a wide field of view, the mirrors are in duplicate; consequently, a moderate change in the expected position of the exploding bomb will not affect observation of the Teller light.

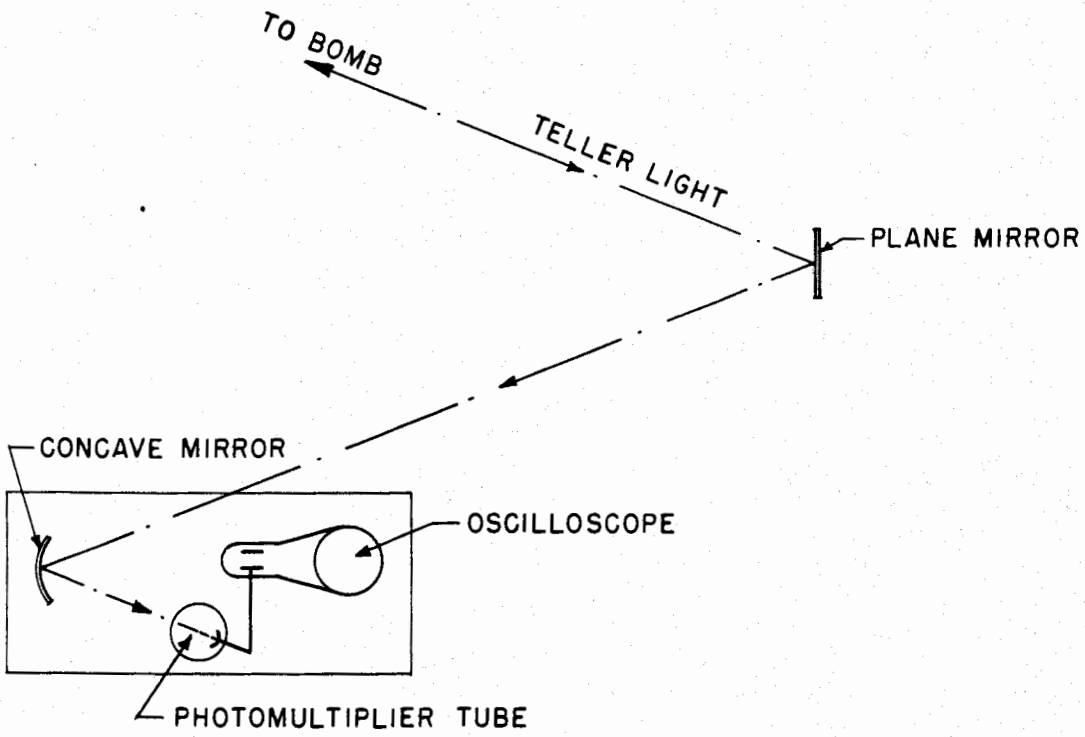


Fig. 6.5

6.5 Determination of Yield

Introduction

The efficiency, ϕ, of a fission device may be expressed as the ratio of the actual number of nuclei undergoing fission to the total number of fissile, i.e., uranium-235 or plutonium-239, nuclei present in the core (Section 2.1). If this is multiplied by the energy which would be obtained by the fission of all fissile nuclei, the result would give the total energy yield.

Something like ten or more different methods, of varying degrees of accuracy, can be used to determine the yield of a nuclear explosion. Two of these, namely, the radiochemical procedure and the ball of fire method, have been generally employed for diagnostic purposes, the others being mainly of secondary interest. Until 1953, the radiochemical method was the only one which gave an absolute value of the yield, and the ball of fire (and other) measurements had to be calibrated empirically with radiochemical data. An important recent advance has been the development of an absolute procedure for calculating yields from ball of fire measurements.

The Radiochemical Method

The efficiency of a nuclear explosion, as defined by equation (2.1), may be written in the equivalent form

$$\phi = \frac{\text{Total number of fissions}}{\text{Number of fissile nuclei in core}} = \frac{F}{U + P} \qquad (6.1)$$

where

F = Total number of fissions (or number of nuclei undergoing fission)

U = Number of U-235 nuclei originally present in core

P = Number of Pu-239 nuclei originally present in core.

It should be noted that whereas F, in the numerator of equation (6.1), includes fissions in all species that may be present or formed in the explosion, e.g., uranium-238, plutonium-240, etc., the quantities U and P in the denominator refer only to the fissile nuclei in the core; uranium-235 present in tuballoy (natural uranium) is not included, neither is any uranium-238 that may undergo fission. Thus, in principle, an efficiency greater than unity is possible, according to the definition given above. *

Suppose that after the explosion a representative ("post-shot") sample of the bomb residues is recovered. By analysis for certain fission products, as described below, it is possible to

*The quantity defined here is sometimes called the "bomb efficiency" to distinguish it from the "core efficiency," i.e., when F = number of fissions in U-235 and Pu-239 only.

determine the number of fissions that have occurred in the sample. Let

f = number of fissions corresponding to sample analyzed

θ = fraction of bomb in sample analyzed,

then

$$f = \theta F, \tag{6.2}$$

and, upon combining equations (6.1) and (6.2),

$$\phi = \frac{f}{\theta(U + P)} \cdot \tag{6.3}*$$

Since U + P may be regarded as known, the determination of the efficiency and yield of a nuclear explosion is reduced to the estimation of f and θ for a given post-shot sample (or samples).

The measurement of f involves the chemical separation of a particular fission product from the sample of bomb residues and the determination of the amount present by means of its radioactivity. The measured activity of the specified fission product is corrected for decay during the time which has elapsed since the nuclear explosion and for possible losses in the chemical separation; if A is the resulting corrected activity, expressed as the rate of particle emission, then it can be shown that

$$A = \epsilon\lambda y f, \tag{6.4}$$

where

ϵ = counter efficiency, i.e., fraction of particles emitted which are actually counted

λ = radioactive decay constant of the fission product

y = yield of the given product in fission.

Although λ and y are known, with moderate accuracy, and ϵ can be measured, it is more convenient to combine $\epsilon\lambda y$ into a single factor. This can be determined by subjecting a small quantity of uranium-235 or plutonium-239 to the action of neutrons, of known density, so that the number of fissions induced can be calculated. Thus, f for a given sample is known. The specified fission product is then separated chemically and counted, so that the activity, A, is measured. Then, from equation (6.4), the corresponding value of $\epsilon\lambda y$, for the particular counter, fission product, and fissile material, can be obtained.

*The symbols used throughout this section are those commonly found in J-Division reports, with two exceptions: the efficiency is represented here by ϕ, as is customary in other LASL reports, and θ is employed for the fraction of bomb in the sample. The J-Division symbols are E and ϕ, respectively.

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The fission products which have been used most extensively in efficiency measurements are molybdenum-99 (half life 67 hours) and zirconium-97 (half life 17 hours). These isotopes have convenient half lifes, and their fission yields, which are among the largest, are not greatly dependent upon the energy of the neutrons causing fission. The λy values for molybdenum-99 are almost identical for fission of uranium-235 and plutonium-239, so that no correction is necessary if the bomb core contains both of these fissile species. For this and other reasons, molybdenum is the preferred isotope. For zirconium, the λy's are slightly different and the value used to determine f depends upon the composition of the core.

The fraction θ of the bomb in the post-shot sample can be determined by analyzing for one of the major constituents, e.g., uranium-235, plutonium-239, or total uranium, and correcting for the amounts lost in nonfission reactions, such as (n,γ), (n, 2n), etc. Since the total amount of each of these species present in the original bomb is known, the fraction of the bomb in the sample can be calculated.

Another method for determining the fraction of the bomb in the post-shot sample makes use of a different principle. A radioactive tracer, in known amount, is included in the bomb before detonation. If the quantity present in the post-shot sample is then measured, the fraction of the bomb in the sample can be calculated. The supposition is here, of course, that the tracer is uniformly distributed throughout the whole of the bomb residues, and this may not be the case. Measurements of this kind have been made with polonium-210 as tracer, but with indifferent success. Nevertheless, it is proposed to make further determinations with this isotope and also with curium-242 as tracer.

Determination of Fraction of Fissions in U-235, Pu-239, and U-238

It is of interest to know what proportion of fissions has occurred in uranium-235, plutonium-239, and uranium-238, respectively. Radiochemical methods have been developed for this purpose, although they are not too accurate. The fraction of the total fissions involving uranium-235 is represented by a, the fraction in plutonium-239 by b, and that in uranium-238 by c, so that

$$a + b + c = 1. \qquad (6.5)$$

Hence, if any two of a, b, c are determined, the third is known.

The value of c can be obtained by utilizing the experimental fact that the ratio of the cross section for the U^{238} (n, 2n) U^{237} reaction to that for the fission of uranium-238 is roughly constant, independent of neutron attenuation in the uranium. Hence, if the amount of uranium-237 in the bomb residue sample is measured, by means of its radioactivity, the number of uranium-238 nuclei which have undergone fission, and hence, c, can be calculated.

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The determination of a and b is possible, in principle, if there are available two fission products which have very different yields (or activities) for the fission of uranium-235, plutonium-239, and uranium-238. Let

R_{25} = ratio of activities for U-235 fission

R_{49} = ratio of activities for Pu-239 fission

R_{28} = ratio of activities for U-238 fission,

so that the observed activity ratio, R, is given by

$$R = aR_{25} + bR_{49} + cR_{28}. \qquad (6.6)$$

Since $a + b + c = 1$, then, if the three activity ratios, R_{25}, R_{49}, and R_{28}, have been determined, any two of the fractions a, b, c, can be calculated provided the third is known. For weapons containing only uranium-235 or plutonium-239 as the fissile material, the problem is, of course, simplified.

Of the pairs of isotopes that may be used in the foregoing connection, one is always chosen to be molybdenum-99; the other may be silver-111, palladium-112, cadmium-115, or cerium-136. Although the method is sound, in principle, it has not yet given satisfactory results. This is believed to be due to a partial separation (or fractionation) of the elements present in the fission products. Consequently, the post-shot samples do not always have the same composition as the bomb residue as a whole. Such is not the case for molybdenum-99, and that is one reason why this isotope is much used in yield determinations.

Provided c is known, a and b can be calculated if the measured ratio of uranium-235 to plutonium-239 in the post-shot sample is compared with the known ratio in the original bomb. This method involves corrections for the amounts of these two isotopes lost in nonfission reactions, as well as for the formation of plutonium-239 as a result of neutron capture by uranium-238, followed by two stages of beta decay.

In a test shot the fraction a can be measured by incorporating into the oralloy an indicator, such as titanium, thorium, thallium, or tungsten. The titanium and thorium react with fast neutrons, i.e., $Ti^{47}(n,p)\ Sc^{47}$ and $Th^{232}(n,2n)\ Th^{231}$, respectively, whereas the thallium and tungsten capture slow neutrons, i.e., $Tl^{203}\ (n,\gamma)\ Tl^{204}$ and $W^{186}\ (n,\gamma)\ W^{187}$ followed by $W^{187}\ (n,\gamma)\ W^{188}$, to form characteristic, identifiable products. By assuming that the uranium-235 and the indicated isotope have been subjected to the same neutron flux, it is possible, from a determination of the product formed and the known cross section of the reaction, to calculate the number of uranium-235 nuclei which have undergone fission.

Somewhat analogous procedures can be used to determine b, except that, as in the method described above for c, the indicator or detector species is already present. In addition to undergoing fission, plutonium-239 is involved in the reaction Pu^{239} (n,γ) Pu^{240} Consequently, if the amount of plutonium-240 present in a post-shot sample is determined, and allowance made for the proportion in the original plutonium and the amount lost in various neutron reactions, the number of plutonium-239 fissions can be calculated. It is of interest to note that the plutonium-240 is determined with a mass spectrograph rather than by its radioactivity. The alpha particles from the 240-isotope are not easily distinguished from those emitted by plutonium-239 because of their similar energies.

Another reaction for determining b is Pu^{239} (n, 2n) Pu^{238} with fast neutrons. In this case, the amount of plutonium-238 in the bomb residue sample can be estimated from its alpha radioactivity since the particles can be resolved from those emitted by the other plutonium isotopes.

The plutonium used in weapons invariably contains some plutonium-241 as an impurity; this is a beta-particle emitter with a half life of 14 years, the decay product being americium-241, half life 470 years. It is seen, therefore, that the plutonium components of bomb cores which have been stored for some time will contain appreciable amounts of americium-241. In the exploding bomb, the latter will undergo the reaction Am^{241} (n,γ) Am^{242}, followed by beta decay of the americium-242 to form curium-242. The curium-americium ratio in the post-shot sample will thus be roughly proportional to the amount of fission which has occurred in the plutonium-239.

Sample Collection

The collection of representative samples for radiochemical analysis after a nuclear explosion has proved to be quite a difficult matter. For reasons not clearly understood, fractionation occurs in the highly complex system, so that a particular portion of the bomb residue may not have the same composition as the average of the whole. In addition to the requirement that the post-shot sample shall be representative, it must be of sufficient size to make accurate analysis possible; it must not be contaminated during collection, and it must be capable of relatively rapid recovery and delivery to the laboratory.

Various methods of sample collection have been tried out at one time or another; the most satisfactory results have been obtained either by the use of drone aircraft guided through the atomic cloud after an explosion or by means of manned aircraft flying into the cloud. The samples collected are of two types: "snap" samples in which a container is filled with essentially gaseous material, and particulate samples obtained by drawing the air and other gases through a filter. The mission of the manned aircraft is planned so as to give satisfactory samples with minimum radiation exposure of the crew.

Attempts have been made to collect post-shot samples in specially equipped rockets fired through the atomic cloud or in heavy bottles placed on the ground so that they are enveloped in the ball of fire. Neither of these, however, has proved as successful as the methods based on the use of drone or manned aircraft.

Efficiency of Thermonuclear Devices

In an explosion of a device involving both fission and thermonuclear reactions, the procedures described above will give only the fission yield. The thermonuclear yield may perhaps also be obtained by radiochemical methods, but the techniques are still in the early stages of development. The basic principle is to determine the density of the 14-Mev neutrons produced by the D-T reaction (Section 1.6) and the result can then be employed to calculate either the amount of burn-up of the hydrogen isotopes or the energy released in the thermonuclear reactions.

To achieve this end, a threshold neutron detector is included in the device. This is an element that reacts with neutrons with energies in excess of a certain threshold value, thereby forming a radioactive product whose amount can be determined by particle counting. Some of the reactions which have been proposed for this purpose and the neutron energy thresholds are quoted in Table 6.1. If essentially only the 14-Mev neutrons are to be detected, then the energy threshold of the detector should be as close to this value as possible.

Table 6.1 Internal Threshold Detectors

Element	Reaction	Threshold (Mev)
Nickel	Ni^{58} (n, 2n) Ni^{57}	11.7
Arsenic	As^{75} (n, 2n) As^{74}	10.4
Scandium	Sc^{45} (n, 2n) Sc^{44}	11.2
Germanium	Ge^{70} (n, 2n) Ge^{69}	11.5
Rhodium	Rh^{103} (n, 2n) Rh^{102}	~ 10
Sodium	Na^{23} (n, 2n) Na^{22}	~ 11
Thallium	Tl^{203} (n, 2n) Tl^{202}	~ 8

The choice of suitable detectors for 14-Mev neutrons has been somewhat restricted by the necessity for the products to be distinguishable from the normal fission products. However, studies are being made of certain elements falling in the fission product range but which form nuclei having a positron activity or a characteristic gamma radiation when they react with fast neutrons. There are apparently no positron emitters among the products of fission.

The Ball of Fire Method

It was seen in Section 6.3 that for an appreciable period of time the growth of the ball of fire is determined by the propagation of the shock front at its surface. Since the shock wave characteristics are dependent on the total energy released in the explosion, it is apparent that there will be a relationship between the size or growth rate of the ball of fire and the yield of the bomb.

Cameras of several different types have been used for this purpose, but two are now regarded as more or less standard. These are (a) the Eastman high-speed, motion-picture type camera, which takes photographs at the rate of about 2,000 frames per second, and (b) the Rapatronic (rapid action electronic) camera, which takes a single frame, with an extremely short exposure at a definite time after the explosion. Although the motion-picture type camera has the advantage of providing a number of successive exposures, the Rapatronic camera, which uses a magneto-optical system in place of a mechanical shutter, produces a clearer picture. In a test shot, several Rapatronic cameras are employed and they are set to give exposures at different times.

The cameras are mounted on towers at known distances from the point of the explosion. Then, from the measured dimensions of the developed image on the photographic film and the focal length of the lens system used, the actual size of the ball of fire, at any given time, can be calculated.

A number of different relative methods for determining yield have been used. They are essentially based on the scaling laws derived from a hydrodynamical treatment of the shock waves arising from "similar" explosions. For two such explosions indicated by the subscripts 1 and 2, the distance traveled by the shock wave, which is equivalent to the radius, R, of the ball of fire, is proportional to the cube root of the energy release or yield, Y, at such a time, t, that R/t is the same in both cases; hence

$$\frac{Y_2}{Y_1} = \left(\frac{R_2}{R_1}\right)^3_{R/t}, \qquad (6.7)$$

where the subscript R/t implies a constant value of this quantity. Thus, if the radius (or diameter) of the ball of fire has been measured at various times for a bomb of known yield, it is possible to determine the yield for any other bomb. As already stated, this ball of fire method is relative, and depends upon a knowledge of yields determined by the radiochemical procedure. Strictly speaking, equation (6.7) applies only when the ambient pressures are the

same in both cases, and appropriate corrections must be made for any differences.

According to the theory of strong shocks, the rate of propagation of the shock front and, hence, in the present case, the rate of increase in the radius or diameter, D, of the ball of fire, is given by

$$D = kt^n, \tag{6.8}$$

where k, for a particular bomb, is a constant related to the yield,* and the exponent n is dependent upon γ, the ratio of the specific heats of the material at the shock front. When γ is 1.4, the value of n is close to 0.4, and then equation (6.8) can be written as

$$D = kt^{0.4}. \tag{6.9}$$

It appears that k is roughly proportional to $Y^{1/5}$, so that a good approximation when n is 0.4, has been found to be

$$Y = C\rho_o k^5 = C\rho_o \frac{D^5}{t^2}, \tag{6.10}$$

where C is a constant determined from observations on the balls of fire produced by bombs of known yield; ρ_o is the density of the ambient air.

To use equation (6.10) for the determination of yields, the data for D at various times t, obtained from the Rapatronic camera films, are plotted and the point found at which n in equation (6.8) is 0.4. Upon substituting the corresponding values of D and t into equation (6.10), the yield can be calculated.

Recently a new, absolute (analytic) method for obtaining yields, independent of scaling principles or knowledge of yield of other bombs, has been developed. It permits the calculation of the total energy produced in the nuclear explosion at any time up to breakaway, using hydrodynamic and thermodynamic principles. According to this method, which takes into account such factors as the transport of radiation in the early stages of the development of the shock front, the large mass of the bomb, and time variations in the equation of state of air and in the ratio of the specific heats at the shock front, the yield may be represented by

$$Y = \frac{F}{32}\rho_o n^2 \frac{D^5}{t^2} \tag{6.11}$$

*The factor k is generally represented by ϕ, but this symbol is used here for the efficiency.

where F is a complex numerical factor which varies from one bomb to another, and even with time for a given bomb. It may be noted that equation (6.11) is somewhat similar to (6.10); however, the empirical constant C in the latter is now replaced by the quantity $Fn^2/32$ which must be determined for each explosion.

The important point of the analytic method is that it has provided a method for evaluating F in each case by the application of hydrodynamic theory to measurements and calculations involving the motion and shape of the shock front, i.e., the surface of the ball of fire, and other available data. The exponent n is obtained at any time, t, in accordance with equation (6.8), from a log-log plot of D as a function of time.

In order to verify the new absolute method, it has been applied to the data obtained in several test shots; it has proved to be a valuable addition to the methods for determining bomb yields. Unlike the radiochemical procedure, ball of fire calculations are applicable directly, without special correction, to devices in which thermonuclear, as well as fission, reactions occur.

Yield Determination: Other Methods

Although the radiochemical and ball of fire measurements have been accepted as the standard procedures for estimating yields, there are other methods, some of which have special advantages. One of these is an absolute method involving a determination of the time interval between the arrival of the shock wave and of the acoustical (sound) wave at a given point. This can be measured with sufficient accuracy with a stop watch; then, knowing the distance from the explosion, the absolute yield can be calculated. A result of fair accuracy can thus be obtained very soon after the explosion.

Another rapid, but relative, method makes use of an instrument called a Bhangmeter. It is a photoelectric device whereby the intensity of the light from the ball of fire is recorded as a trace on an oscilloscope with a retentive fluorescent screen. The trace is photographed with a Land (Polaroid) camera which permits immediate, in situ, development of the exposed film. The elapsed time between the explosion and the first luminosity minimum (see Fig. 6.4), i.e., the breakaway time, can thus be determined very quickly.

It is evident from the discussion in Section 6.3 that this time interval is essentially that during which the shock front coincides with the luminous surface of the ball of fire. Consequently, a relationship between the breakaway or luminosity minimum time and the yield of the explosion is to be expected. It has been found empirically, from measurements on various tests shots, that

$$Y \approx 0.038t^{2.3},$$

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where Y is the yield in kiloton units and t is the time in milliseconds to the luminosity minimum. Although the accuracy of the Bhangmeter method is probably ± 15 per cent, it has the advantage of giving a yield value within a few minutes of the explosion.

The other methods of yield determination do not appear to possess any special advantages in most instances, although they may be valuable in special cases. Their main interest lies in the fact that they relate the yield to other phenomena accompanying the explosion. Thus, the total gamma-ray dosage, the thermal radiation, and the slow neutron flux are dependent, in a more or less definite manner, on the energy yield. Some reference to these matters will be made below.

6.6 General Test Experiments

Gamma-Ray Measurements

The experiments already described for the determination of α give the time variation of the prompt gamma-ray intensity. When scintillation counters of known efficiency are used, it is possible to calculate the total number of prompt gamma rays escaping from the bomb, provided their mean free path (or absorption coefficient) in air is known. Although this number is approximately proportional to the bomb yield, it is influenced by the tamper thickness, the material surrounding the tamper, and other structural factors.

The change with time in the intensity of the delayed gamma rays, coming mainly from the fission products, has also been determined. Because of the very large range of the intensities, scintillation detectors with logarithmic attenuators have been used. Thus, a quantity related to the logarithm of the gamma-ray intensity, rather than to the intensity itself, is recorded.

Of particular interest from the radiological standpoint is the total gamma-radiation dosage as a function of distance from the explosion. This quantity, expressed in roentgens, is determined by exposing photographic films at various points; the blackening of the films, from which ordinary light is excluded, is a measure of the radiation dosage received. As a fair approximation, the results may be expressed by

$$\text{Total Dosage} \approx 1.9 \times 10^{9} \frac{Y}{D^2} e^{-\frac{D}{\lambda}} \text{ roentgens,} \qquad (6.12)$$

where

Y = bomb yield in kt

D = distance from explosion in meters

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λ = mean free path of gamma radiation

$$= 370 \times \frac{1.12 \times 10^{-3}}{\rho}$$

ρ = density of air in g/cm^3.

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At a specified distance from the explosion, the radiation dosage is seen to be roughly proportional to the yield, for a given density of air.

Neutron Measurements

Neutron measurements have been made at test shots for a variety of purposes. Among these may be mentioned the following: energy spectrum of neutrons, neutron flux as function of time, and total number of neutrons arriving at different distances from the explosion. In addition, neutron measurements have been found particularly useful for the study of thermonuclear processes.

The neutron spectrum from a nuclear explosion is studied by means of a number of (external) threshold detectors (see Section 6.5) placed at a given location at a known distance from the bomb. The most important detector elements, the reactions they undergo, the half lives of the products, and the neutron energy thresholds are given in Table 6.2. Depending on its thickness and cross section, a definite fraction of all neutrons having energies above the threshold value are captured by a given detector, and from the radioactivity acquired, the total

Table 6.2 External Threshold Detectors

Element	Reaction	Half Life (days)	Threshold (Mev)
Gold	Au^{197} (n,γ) Au^{198}	2.69	Slow
Sulfur	S^{32} (n,p) P^{32}	14.3	3.0
Iodine	I^{127} $(n,2n)$ I^{126}	13.0	9.45
Zirconium	Zr^{90} $(n,2n)$ Zr^{89}	3.25	12.0

number of neutrons in various energy ranges can be determined. If the gold is covered with cadmium, only neutrons with energies of about 0.18 ev are detected. By exposing detectors at several distances, the neutron intensity is found as a function of distance.

The neutron spectrum can also be studied by the Phonex (photographic neutron experiment) method using nuclear track plates, i.e., plates coated with a special emulsion that records individual tracks of charged particles. A collimator channel, through a thick gamma-ray shield, produces an essentially unidirectional beam of neutrons which bombard a thin layer of polyethylene (Fig. 6.6). The recoil protons thus produced, at known scattering angles, are detected by the nuclear track plates. The corresponding neutron energies can be calculated from the lengths

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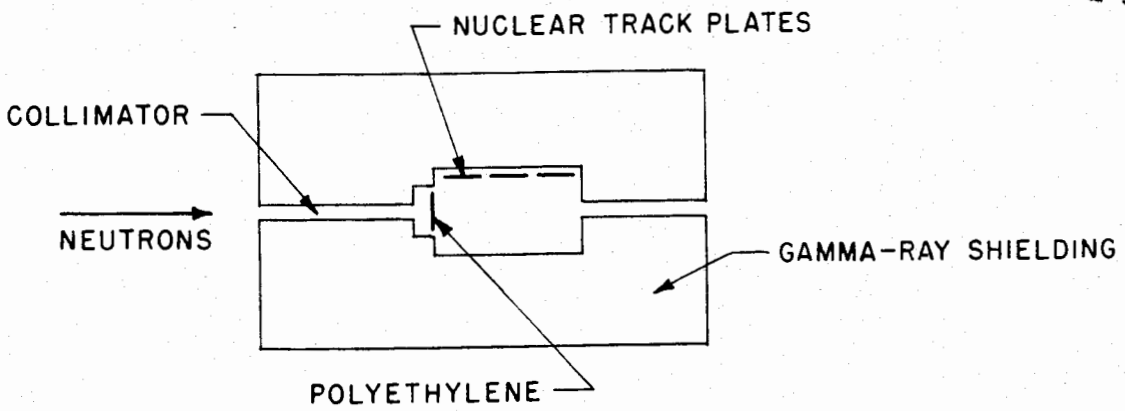


Fig. 6.6

of the proton tracks after development. The number of tracks of various lengths provides an indication of the distribution of the neutrons over a range of energies. The Phonex method can be adapted to study the 14-Mev neutrons liberated in the D-T reaction for the purpose of determining the burning temperature; the general principles are described in Section 6.10 (Tenex measurements).

The neutron dosage decreases with increasing distance from the explosion in an exponential manner, as is to be expected, but there is no simple relationship between the neutrons received at any point and the bomb yield. In view of the somewhat indefinite secondary character of the neutron emission, as indicated in Section 6.3, this is perhaps not too surprising.

The time dependence of neutron emission is determined by means of a "fission catcher." A strip of cellophane is drawn, at a known rate, past a thin uranium foil exposed to neutrons from the atomic explosion. As the neutrons are captured they cause fission in the uranium, and the radioactive products are collected on the cellophane. The variation of activity along the strip is then a direct measure of the variation of the neutron flux with time.

Determination of Compression

b(3)

The results were not too decisive, but the method is, nevertheless, of interest, since it is the only one developed so far whereby compressions in an actual test shot might be determined.

b(3)

If a

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known number, n_o, of these neutrons enter a thickness x of material in which they are attenuated, either by absorption or scattering, the number, n_x, which emerges is given by

$$n_x = n_o e^{-N\sigma x}, \qquad (6.13)$$

b(3)

[redacted]

From the results, and the known cross section, it is possible to determine the thickness, x, of the material by equation (6.13). Hence, the compression at the time of an implosion can be calculated. It should be noted that the quantity N in equation (6.13) depends on the density of the material and, so, also on its compression.

6.7 Shock Wave Measurements

The Mach Effect

In order that nuclear weapons may be used most effectively, it is necessary to study various properties of the shock wave and related phenomena. The information obtained in this manner can also be utilized for the development of defensive procedures. For these and other reasons, various measurements of shock wave phenomena are undertaken in connection with nuclear weapons tests.

When the shock wave from an explosion strikes the ground, a reflected wave is produced which travels faster than the original shock. As a result, at a certain distance beyond the zero point, the reflected wave overtakes the direct one and the two shocks merge into a single shock. This phenomenon is called the Mach effect. The region near the ground where the direct and reflected shocks merge is called the Mach stem, and here the pressure is considerably greater than that of the individual shock waves. The point--in reality a circle--where the direct, reflected, and Mach shocks meet is referred to as the triple point. Its path, as it moves outward from the explosion point, is known as the triple point path (Fig. 6.7). The investigation of the Mach effect is an important aspect of shock wave studies.

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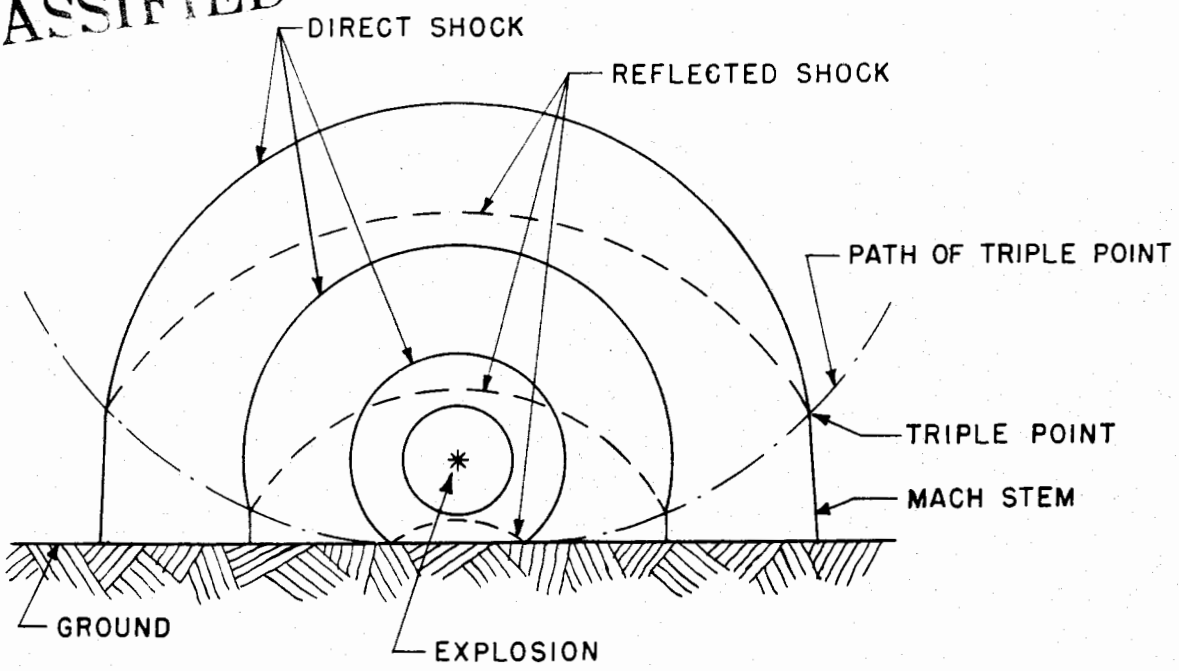


Fig. 6.7

Free-Air Peak Pressure

The shock pressures in the air above the triple point path, i.e., where the Mach effect is not apparent, are called the free-air pressures; these can be determined by observing the time of arrival of the shock front at a series of points at known distances from the explosion. From these times of arrival the shock velocity can be determined and the maximum or peak pressure at various distances can then be calculated from shock-wave theory.

One method used for observing shock arrival times was to attach blast switches to a number of cables held by balloons. Upon arrival of the shock, the switch closes and sends a signal to a distant receiving station, by cable or radio. This procedure has been found to be rather expensive and so it has been replaced by the method of rocket-trail photography.

In passing through a region occupied by a shock front, light is refracted, so that objects seen through the shock wave appear to be distorted; this fact permits times of shock arrival to be determined. Just prior to the explosion, a fan-like grid of vertical smoke trails is produced from a number of rockets launched from the ground at various distances from the zero point. These trails are photographed with a motion-picture camera, at about 100 frames/sec. The arrival of the shock front at a point between the camera and any trail is indicated by an

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apparent shift in position of the trail due to refraction. The method can be used to determine shock pressures as high as 10,000 psi.

Material Velocity Measurements

Material velocity or mass-motion studies have been found to be a useful means of determining free-air peak pressures as a function of distance and also as a means for studying many hydrodynamic variables associated with shock waves. The general principle of the mass-motion method is to label a parcel of air with smoke and then to record photographically, with a motion-picture camera, the movement of the visible cloud when struck by the shock wave. From the displacement of the cloud and the camera speed, a displacement-time curve can be obtained. The maximum slope of this curve gives the material velocity associated with the peak shock pressure. Then from the shock-wave theory, this pressure can be calculated. The mass-motion procedure is probably most valuable at distances where the shock pressure is not too high.

Three methods have been found satisfactory for labeling a region of the air with smoke. These are, first, the use of a jet-assisted take-off (JATO) unit on the ground, with its nozzle pointing upward. Upon ignition this produces a vertical column of white smoke, extending for about 150 feet, which can readily be photographed. The second method utilizes aerial, fireworks bombs ("aerial salutes"); these are fired vertically from a mortar and produce a visible puff of smoke at 100 to 350 ft in the air. Finally, for considerable heights above the ground, smoke shells, fuzed to explode at the desired altitude, are shot from a 90-mm antiaircraft gun.

Mach-Region Peak Pressures

The rocket-trail method described above has been found to give information concerning the Mach triple point path and the shape of the Mach stem in its early stages, as well as of pressures in the Mach region. For studies at or near ground level, arrival times can be determined by means of blast switches or by various methods of direct pressure measurement. Such direct observations are usually restricted to shock pressures below about 100 psi. Several types of pressure gauge have been used for this purpose with more or less success. Mention may be made of foil, indenter, and Wiancko gauges.

The foil meter has a series of thin metal diaphragms of different diameters, so that different pressures are required to rupture them. The maximum diameter not ruptured indicates the maximum shock pressure at that point. In the indenter gauge, the pressure is determined from the indentation produced in a sheet of copper. However, at the present time it is believed that the Wiancko guage, which is a modification of the Bourdon pressure gauge, will prove most satisfactory.

Pressure-Time Measurements

Measurements of the shock pressure as a function of time are usually made on the ground; the indicators may be of the self-contained type or they may be connected, to recorders at a distance. For pressures less than about 50 psi the signals from Wiancko gauges may be transmitted by buried cable to be recorded on magnetic tape at a receiving station. The tape record then provides an indication of the variation of shock pressure with time. For somewhat higher shock pressures, e.g., up to about 120 psi, the inductance gauge has been used. In this device a change in pressure causes a diaphragm to move and this causes a variation in the inductance of an oscillator. The resulting frequency modulated signal, after amplification, is transmitted to a station and recorded on magnetic tape.

The self-contained instrument for determination of the time variation of shock pressure consists of a mechanical piston driven by the pressure against a spring restoring force. The piston, damped with oil of suitable viscosity, has a stylus attached, and this scratches a record directly on a rotating drum coated with graphite.

Another, somewhat more elaborate, method for studying the shock pressure near the ground as a function of time makes use of an interferometer gauge. The pressure-sensitive element is a circular quartz diaphragm which is part of an optical system producing a circular pattern of interference rings when illuminated with monochromatic light. When pressure is applied to the diaphragm, its motion, which is proportional to the pressure, causes a change in the number of lines in the interference pattern. From this change, the applied pressure can be determined. The interference pattern is recorded over a short period of time by means of a high-speed, moving-film camera.

Air Density in Shock Waves

An instrument, called a beta densitometer, has been developed for determining the variation with time of the density of air in the shock wave. The essential principle is that the number of beta particles from a given source which can penetrate, i.e., not be absorbed by, a layer of air of a certain thickness depends on the density of the air. Strontium-90, of 1 curie strength, is used as the beta-particle source, and a scintillation device with a photo-tube is the detector. From the observed intensity of the beta radiation, the density of the air between the source and the detector can be estimated.

The problem to be solved is how to eliminate the effect of the background radiation which will inevitably be considerable after an atomic explosion. Two methods have been used to achieve this end. In the first of these, two detectors are employed: one is exposed to the beta particles and the background radiation and the other to the background alone. The readings from the detectors are balanced against one another and the results give an indication of the

beta-particle intensity. In the other method only one detector is required, but in front of it is a rotating "chopper" which cuts off the beta radiation at definite intervals. The difference in the detector response with and without the chopper is a measure of the beta radiation.

Other Shock Measurements

In addition to the foregoing, various other measurements of shock and blast phenomena may be made in connection with a weapons test. Special gauges are used to determine the high pressures close to the exploding bomb, and the variation of the pressure with height above ground has been observed with gauges attached to pylons. Shock wind velocities are measured with double-ended Pitot tubes and ground shock with standard self-recording accelerometers or by means of seismic devices which record displacement. In the case of underground or underwater detonations, various studies of arrival times and shock pressures are made beneath the surface of the earth or water, respectively.

6.8 Spectroscopic and Radiation Measurements

Spectroscopic Studies

Spectroscopic studies of the radiations from a nuclear explosion are made for a variety of purposes. Among these are the following: determination of the temperature and energy distributions at the surface of the ball of fire as a function of time; investigation of the space distribution of various materials in the ball of fire; and identification and variation with time of the light-absorbing molecules and ions formed in front of the bomb, due largely to the action of gamma radiations and high temperatures on the gases present in the atmosphere.

The type of spectrograph and associated equipment employed depends on the main object of the particular observation. High-dispersion (concave grating) instruments are used, with stationary photographic plates, to provide detailed information concerning the total bomb light. On the other hand, for time variation studies, high-speed (quartz prism) spectrographs are required, but these have only moderate dispersion, so that less detail is available. The spectra at definite intervals are recorded by means of motion-picture type, framing cameras. To determine the space distribution of materials over the fireball, the image of the latter is focused on the center of the viewing slit of the spectrograph. Each point on a spectral line can be related to a definite location on the fireball surface, and so information concerning space distribution of the spectrum, and of the materials responsible, may be secured.

An analysis of the spectra obtained around the first luminosity minimum (Fig. 6.4) makes it possible to identify the various substances formed in front of the ball of fire. These include normal, excited, and ionized molecules of oxygen and nitrogen, ozone, atomic oxygen and

probably nitrogen), water molecules, hydroxyl radicals, nitric oxide, nitrogen dioxide, and nitrous acid (HNO_2) molecules.

In the later stages of development of the ball of fire, usually after the minimum, spectral lines due to elements present in the bomb begin to appear.

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The conditions are, in general, not favorable for the observation of lines due to uranium, plutonium, and fission products. This has been attributed to the strong iron spectrum, which masks the lines of many other elements, to absorption by the atmosphere, and to other factors.

The apparent (or black-body) temperature of the surface of the ball of fire is determined as a function of time by measuring the ratio of the spectral flux intensities in two wavelength regions, e.g., around 3700 Å and 6200 Å. From this ratio, the temperature of an equivalent black body, to which the ball of fire is a good approximation, can be derived by using the Planck radiation law. The flux measurements are made with photoelectric cells equipped with suitable filters that permit the passage of radiations within a narrow band. The signals from the photocells are amplified and recorded by means of oscilloscopes and attached moving-film cameras.

Transmission of Radiation

An important aspect of radiation measurements is the determination of the transmission of radiation as affected by absorption and scattering due to molecules and dust particles present in the air. The transmission is strongly dependent on the density, humidity, and clarity of the atmosphere, so that the existing conditions will affect both ball-of-fire photography and thermal radiation measurements. Since the former is of great significance in determining bomb yields, transmission measurements are often made prior to a test shot to make sure that good photographs of the ball of fire will be obtained.

A searchlight of known luminous intensity is set up close to zero point and a focused beam of light from it falls on a photocell several miles away. The beam is modulated at 60 cycles/sec by a mechanical chopper and the receiver system is designed so that it will detect and record light at this modulated frequency only. The system will consequently be independent of daylight. The transmission of the atmosphere is then evaluated from the intensity of the light received by the photocell.

Thermal Radiation Measurements

All the energy of a bomb ultimately appears as thermal radiation or heat, but the portion released within the first minute or two of the explosion, due to the high temperature of the

fireball surface, is of special interest. This has been referred to in Section 6.3 as the prompt or effective thermal radiation. The latter description is applied because it is this radiation which is responsible for skin burns, and possibly of fires out to considerable distances from a nuclear explosion. Prompt thermal radiation studies are thus of interest, not only because they provide information concerning the phenomena of a nuclear explosion, but also because of the importance of these thermal radiations from the weapons standpoint. Measurements are usually made of the total energy released as prompt thermal radiation and of the energy variation with time.

The total prompt thermal radiation is measured in two ways. One method makes use of a conventional ballistic thermocouple, the output of which is measured with a thermopile recorder connected to a photoelectronic galvanometer. In the other method a blackened container is filled with air which expands, due to the temperature increase, when radiation is absorbed. The amount of the latter is calculated from the movement of a diaphragm indicator. By using data for the transmission of radiation by the atmosphere just prior to the explosion, such as those described earlier, the total energy liberated by the bomb as prompt thermal radiation can be estimated.*

It was thought at one time that a definite fraction of the energy of the explosion appears as prompt thermal radiation. More recent measurements have shown, however, that this fraction varies with the bomb yield. The results can be expressed, to a fair degree of accuracy, by the relationship

$$Y_{th} = 0.42Y^{0.9 \pm 0.04} \qquad (6.14)$$

where the prompt thermal radiation yield, Y_{th}, and the total bomb yield, Y, are expressed in kilotons. It follows, therefore, that for a 20 kt bomb about 28 per cent of the energy is released as prompt thermal radiation, but in a 100 kt bomb the proportion is only 23 per cent.

The amount of radiation energy, Q, delivered per unit area at a distance D from the explosion is represented by

$$Q = \frac{Y_{th}}{4\pi D^2} e^{-kD} \qquad (6.15)$$

where k is the attenuation coefficient of the air for the thermal radiation emitted in the explosion. The value of k, which determines the transmission of radiation, depends on the state

*The transmission coefficient depends to a marked extent on the wavelength of the radiation and this must be taken into account in the calculation.

of the atmosphere between the bomb and the point of observation. It can be determined by direct observation of the value of Q at various distances and substituting in equation (6.15) or it can be calculated from transmission measurements.

The thermal radiation intensity is determined as a function of time either by a high-speed bolometer or by means of photoelectric cells. In the bolometer, which has a resolving time of about 25 μsec, a rapidly rotating "chopper wheel" is used to provide successive short exposures of a blackened platinum wire several thousand times per second. From the time change of resistance with temperature, the rate of variation of the radiation intensity can be found. The purpose of the "chopper" is to modulate DC voltage, so that the resulting AC output can be amplified and recorded on magnetic tape.

For very short times, e.g., 0.1 to 100 μsec, after the explosion the change in radiation intensity within a certain wavelength band can be measured by photocells, with suitable amplification, e.g., by means of a photomultiplier tube. The instantaneous current is a measure of the instantaneous radiation intensity in that particular wavelength range reaching the cell.

6.9 High-Speed Photography

High-Speed Framing Cameras

Observations of the ball of fire in the very earliest stages of development are of interest since they provide information concerning the transition from radiation to shock phase, on the effects of the yield-to-mass ratio, and on the perturbation of the fireball due to proximity of the earth's surface. These data are required to permit refinement of hydrodynamic theory as applied to growth of the ball of fire. Neither the Eastman motion-picture camera nor the Rapatronic camera used in ordinary fireball measurements (Section 6.5) is quite suited to this purpose. The former because of the relatively low frame rate and the latter because each camera gives only a single exposure.

The problem has been solved by means of high-speed, framing cameras. Three models are in general use, their nominal frame rates being 5×10^4, 9×10^4, and 3.5×10^6 frames/sec, respectively. By means of such cameras a considerable number of photographs of the ball of fire can be made during the first hundred microseconds after the explosion.

The high frame rates are achieved by using a rotating mirror to reflect images in turn on to a number (50 to 100) of lenses, each of which focuses an image upon a section of strip film. Although the mirror rotates continuously at high speed, the camera is so designed that the action is effectively, although not actually, stopped each time the mirror reflects light on to one of the lenses. From the known angular velocity of the rotating mirror and the distance between the lenses, the time for each frame can be calculated.

Because of the very short exposures, the attenuation of light between the ball of fire and the camera, several miles away, is very important. It is necessary, therefore, to monitor the light path prior to the test shot, by the method already described, if high-speed photography is to be used for ball-of-fire measurements.

Rotating Mirror (Streak) Cameras

The rotating mirror, streak cameras used in weapons tests are essentially the same as those described in Chapter 4 for testing detonators and HE lenses. A rotating mirror reflects light continuously from a number of sources on to a film strip; the distance between the points at which the traces from the different sources commence is a measure of the time interval between the initiation of the respective sources. The writing speed is such that 2 mm is equivalent to 1 μsec. The essential purpose of the streak cameras in weapons tests is thus to determine elapsed time between two or more events.

One such use is to measure the time interval between the fission and fusion reactions in separate parts of a two-stage thermonuclear device. Each type of process will induce Teller light (see Section 6.4) in the surrounding air, so that two streaks will appear on the camera film. The distance between the beginning of the two streaks gives the time between the two reactions.

Another application of the rotating mirror, streak camera is to determine shock velocity and pressure within a device by studying so-called "hot spots." These are points (or small areas) down the length of a case at which the arrival of the shock front from a fission bomb is indicated by strong light emission. By means of a pipe and mirror arrangement, the camera observes only certain selected points, the light from all other parts of the bomb being blocked out. From the positions of the streaks indicating the arrival of the shock front at successive points a known distance apart, the velocity and shock wave and, hence, the shock pressure can be calculated.

The propagation of the shock wave through a particular metal, which is part of the bomb case, can also be studied by the hot-spot procedure. This is done by making the shock wave traverse different thicknesses of the metal, by drilling the bomb case at some points and adding pads of the same material at others. The various spots will thus become luminous at different times and the intervals between them can be estimated from the camera streaks.

6.10 Thermonuclear Burning Studies

Tenex Measurements

The primary purpose of the Tenex (temperature neutron experiment) measurements is to make use of the 14-Mev neutrons produced in the D-T reaction to estimate the thermonuclear

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burning temperature. Strictly speaking, these neutrons have an energy of 14 Mev only if the reacting deuterium and tritium nuclei are at rest. But if these nuclei are in motion, the neutron energy will be 14 Mev plus four fifths of the kinetic energy of the reacting particles in the center-of-mass (C-of-M) system. Actually the center of mass is in motion relative to the observer, so that there is a Doppler energy shift superimposed on the energy in the C-of-M system. Consequently, neutrons released in the D-T reaction will have energies covering a band in the vicinity of 14 Mev. The higher the velocity of the particles, i.e., the higher the nuclear temperature, the broader the band. The velocity distribution is roughly Gaussian, with the half width depending on the temperature.

A scintillation detector is placed at a considerable distance from the explosion, so that neutrons of different energies belonging to the 14-Mev group arrive at different times. These are recorded on a synchroscope, and the velocity distribution can then be determined from the observed "times of flight." From this distribution, the temperature of the thermonuclear reaction system can be estimated. *

When studying thermonuclear devices of high energy yield, the recording instruments must be located a considerable distance away. If the detectors can be placed near the explosion point, long cables are necessary to transmit signals to the recorders. Such lines must be protected from extraneous gamma radiations by extensive earth fills which are costly. On the other hand, if the detectors are close to the recording instruments, the radiations from the bomb, e.g., neutrons and gamma rays, suffer considerable attenuation due to absorption, so that weak signals are received.

In the Ivy tests the problem was solved by transmitting the radiations through a helium channel since this gas is a poor absorber for both neutrons and gamma rays. The channel consisted of a plywood box, 8 ft by 8 ft in cross section and nearly 9,000 ft long, filled with a number of thin-walled polyethylene balloons containing helium gas at slightly above atmospheric pressure. Lead baffles inserted in the box served to provide a number of well-collimated paths, which were used for Tenex and other measurements related to thermonuclear burning.

In order to reduce attenuation still further, an evacuated metal pipe, 6 inches internal diameter and about 7,500 feet in length, is to be used as the radiation path in the Castle tests. A pressure of 0.1 atm is believed to be adequate for the purpose, although it is expected that a much higher vacuum will be maintained.

*The energy distribution can also be determined, and the temperature estimated, by the Phonex measurements described in Section 6.6.

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Dinex Measurements

The progress of the thermonuclear D-T reaction as a function of time can be studied by following the rate of emission of the 14-Mev neutrons. This may be done by the Dinex (diagnostic neutron experiment) method.

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Because of the very short time scale, allowance must be made for the time of flight of the neutrons over the distance from their origin to the detector. This requires a knowledge of the neutron energy and makes it necessary to keep out scattered neutrons since the distance they have traveled is uncertain.

The neutrons enter through a collimator, which serves to define their direction and to eliminate scattered neutrons, and then bombard a hydrogenous material, e.g., polyethylene, as in Fig. 6.6, The recoil protons pass through a magnetic analyzer which accepts only those protons produced by 14-Mev neutrons. These protons fall upon a collector, which is essentially a Faraday cage giving a current of the order of 10^{-19} amp per proton per second. Every proton collector is made to drive a bank of cathode-ray oscillographs, each unit being attached to a recorder of different sensitivity. This procedure is necessitated by the very large range of signal levels, from initiation to the peak of the thermonuclear burning. With the arrangement described, each instrument records over a different range of proton and, hence, 14-Mev neutron, intensities. From the oscillographic records, the rate of emission of the 14-Mev neutrons can be determined.

Ganex Measurements

The Dinex method requires a large amount of shielding to prevent gamma radiation from reaching the proton detector. This problem has been overcome in the Ganex (gamma-ray neutron experiment) method for measuring the time variation of the 14-Mev neutrons as an indication of the rate of the D-T reaction. The 14-Mev neutrons, after passing through a moderately good collimator, fall upon a "converter" of iron. As a result, these neutrons are inelastically scattered by the iron nuclei and inelastic scattering gamma rays are thereby produced. Some gamma radiation also arises from (n,γ) capture in the iron. A scintillation detector is placed behind a collimator which points at the converter and the gamma-ray output is observed, as a function of time, by means of an oscilloscope.

One advantage of the Ganex method is that the converter can be placed near the neutron source and the gamma radiation is then transmitted through the air to the detector some distance away, without the necessity of using long cables. However, the lack of good energy discrimination makes the procedure unsatisfactory at low gamma-ray levels because of interference by radiations from extraneous sources. This difficulty is partially overcome by the use of a helium or vacuum path for the gamma radiations, as described in connections with the Tenex measurements.

Gamma-Ray Experiment

A method for studying the time characteristics of D-T burning makes use of the gamma radiation accompanying the reaction. In this experiment it is essential that the gamma-ray beam should be well collimated and that the collimator should point at the region of the bomb where the thermonuclear processes are occurring. The gamma rays are observed by means of a scintillation detector connected to an oscilloscope; the time variation of the observed signal is then directly related to the progress of the thermonuclear burning.

For the George experiment (Operation Greenhouse) the detector was placed near the device and the signal was carried by buried cables to the oscilloscope which was not too far away. In the Mike (Ivy) shot, however, for the reasons given above, the gamma radiation was transmitted through a collimated channel in the long helium-filled box described earlier. For the Castle tests, the vacuum pipe referred to above will be used.

X-Ray Experiment

Nuclear reaction temperatures can be determined by utilizing the fact that at these temperatures the "thermal" radiation emitted is in the soft X-ray region, with energies in the range from 1 to 10 kev. From the energy or wavelength of this radiation, it is possible to estimate the temperature of the emitter. The method is usually not applicable to fission bombs because of the considerable absorption of the X-rays by the bomb materials. But for certain thermonuclear devices, where the absorption is not so great, the X-ray method can be used to derive reaction temperatures.

There are several difficulties associated with the measurements, among which may be mentioned the following: the 1 to 10 kev region has been little studied; a very high time resolution is required because of the rapidity of the thermonuclear burning; and the detecting devices must cover a wide range of intensities. The method used with some success at the Greenhouse tests was to permit the "thermal" X-radiation from the experimental device to travel down an evacuated pipe and to fall on a detector, called a fluorescer. This is a foil coated with a compound of either potassium, manganese, or copper; these elements are sensitive to X-rays in the regions just above 3.6, 6.5, and 9.0 kev, respectively.

If X-rays of the appropriate energy strike the fluorescer, one of the K-electrons of the element present will be ejected; when its place is taken by another electron, the characteristic K-radiation of either potassium, manganese, or copper will be emitted. This is allowed to fall upon an aluminum surface shielded from the direct X-ray beam, and as a result photoelectrons are produced. The electrons are accelerated by a high voltage and the resulting signal can be recorded on an oscilloscope. By observing which of the fluorescers produces its characteristic X-radiation, an estimate may be made of the energy of the primary (thermal) X-rays and hence of the temperature of the material emitting them.

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6.11 Summary of Weapons Tests

In the following pages there is given a summary of the characteristics of the nuclear weapons and devices which have been detonated up to the end of 1953. A brief indication is included of the composition of the core, the prime purpose of the test, and the yield in each case.

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Code Name	Date	HE System *	Description	Initiator	Yield (kt)	Purpose and Remarks
Trinity	7/16/45				24	First test of (implosion-type) nuclear weapon
Hiroshima	8/ 3/45				13 (?)	Combat drop. First test of gun-type nuclear weapon
Nagasaki	8/ 9/45				23 (?)	Combat drop of implosion-type weapon
Crossroads	Summer 1946					
Able					22	Effects test on ships of air burst
Baker					23	Effects test on ships of underwater burst
Sandstone	Spring 1948					
X-ray					37	
Yoke					48	
Zebra					18	

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Code Name	Date	HE System	Description	Initiator	Yield	Purpose and Remarks
Ranger	Jan-Feb 1951					
A(Able)					1.2	
B-1(Baker 1)					7.8	
B-2(Baker 2)					7.95	
E (Easy)					1.00	
F (Fox)					22	

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Code Name	Date	HE System	Description	Initiator	Yield	Purpose and Remarks
Greenhouse	Spring 1951				82	
Dog (How'')					47	
Easy					250	
George					46	
Item (Booster)					~ 0	
Buster-Jangle	Fall 1951				3.5	
					14	

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Code Name	Date	HE System	Description	Initiator	Yield	Purpose and Remarks
Buster-Jangle (continued)	Fall 1951				21	
					31	
					~ 1.2 (?)	
					~ 1.2 (?)	
Tumbler-Snapper	Spring 1952					
TS 1					1.4	
TS 2					1.4	
TS 3					31	
					20	

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Code Name	Date	HE System	Description	Initiator	Yield	Purpose and Remarks
Tumbler-Snapper (continued)	Spring 1952				13	
					12	
					17	
					18	
Ivy	Nov. 1952				>11,000	
Mike					550	
King						

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Code Name	Date	HE System	Description	Initiator	Yield	Purpose and Remarks
Upshot-Knothole	Spring 1953				17	
					24	
					~ 0.2	
					11	
					28	
					~ 0.3	
					26	

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Code Name	Date	HE System	Description	Initiator	Yield	Purpose and Remarks
Upshot Knothole (continued)	Spring 1953				32	
					15	
					61	

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Chapter 7

Laboratory Organization and Activities

7.1 History and Responsibilities

The Los Alamos Scientific Laboratory was established in April 1943, at Los Alamos, N. M., on the site of the 25-year-old Los Alamos School for Boys. Operated from the first by the University of California, its purpose has been to carry out experimental and theoretical work in connection with the military applications of nuclear energy. The Laboratory was originally planned as a temporary installation to make atomic weapons for World War II. However, even before 1947, when the University of California's contract to operate the Laboratory was transferred from the Manhattan Engineer District to the Atomic Energy Commission, it was apparent that the Laboratory would have to be continued for an indefinite period in the interests of national security. It has now become a permanent plant with outstanding equipment and facilities for research and development in both fundamental and applied aspects of nuclear energy.

The operations of the Laboratory embrace, of necessity, much more than direct weapons work. The improvement of current weapons design and the development of weapons of new types requires much basic research in a host of scientific and technical fields. But, because the main concern of the Laboratory is with nuclear weapons, such research is invariably of a character which will provide a better understanding of the complex processes associated with fission and thermonuclear reactions.

The general responsibility of the Laboratory is for the design and development of systems for effecting supercritical assemblies of fissile material, and for the design of high-explosive, nuclear, and related components for atomic weapons. Components outside of those which produce the supercritical system are the responsibility of other installations, such as the Sandia Corporation at Albuquerque, N. M., which is concerned primarily with ordnance engineering details. However, since the nuclear, ordnance, and other aspects of a weapon cannot be completely separated, close liaison is maintained by the Laboratory with other agencies.

Since the Laboratory is not intended to be a production unit, fabrication of components is restricted to a few prototype specimens which are used either for experimental and test purposes or as samples. Large-scale production of items designed in the Laboratory is carried out by other AEC contractor establishments, although such work is done to specifications laid down by the Laboratory. The Laboratory also establishes procedures for the surveillance and testing of components which it has designed. This again requires cooperation by the Laboratory with outside AEC contractors.

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7.2 Laboratory Organization and Personnel

The organization of the Laboratory is made up of the Director's Staff, eight Technical Divisions, each divided into several more or less separate Groups, and a number of Administrative and Service Departments and Groups. From time to time special (DIR) projects of an exploratory nature are established; these remain under the supervision of members of the Director's Staff until they have reached the stage where they may be transferred to one of the Technical Divisions.

Certain aspects of the work of the Laboratory are guided by technical committees. Some of these are permanent but most are of a temporary character, being set up to deal with a specific project (or projects) involving the activities of several Divisions. These committees may consist solely of members of the Laboratory or they may include representatives of other agencies, such as the Sandia Corporation, the Armed Forces Special Weapons Project, the Air Force Special Weapons Command, Bureau of Ordnance (Department of the Army), etc.

An outline of the activities of each of the Technical Divisions of the Laboratory is given below, as well as brief statements of the main functions of the Administrative and Service Departments and Groups. It is perhaps redundant to state that the Laboratory is made up of individuals, and that the progress of the Laboratory is determined entirely by the ideas and activities of the men and women it employs. Since it is impossible to mention in this Report all who have contributed materially to the Laboratory's progress, the names are given only of those holding senior positions on the Director's Staff, in the Technical Divisions and their constituent Groups, and the Administrative and Service Departments and Groups. Unfortunately, this compromise fails to give recognition to many who merit it, but it is the best that can be done in the circumstances.

At the present time, at the beginning of 1954, the Laboratory has about 2800 full-time employees, of which nearly 900 are members of the professional (medical and scientific) staff, the remainder performing administrative, secretarial, and technical services. The professional staff is divided into two categories, namely, staff members and research assistants; their academic standing is indicated by the numbers in the following table.

	M.D.	Ph.D.	M.S.	B.S.	Total
Staff Members	8	313	116	283	781
Research Assistants	-	-	25	77	107

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7.3 Director's Staff

Director	Norris E. Bradbury
Technical Associate Director	Darol K. Froman
Special Assignments	Marshall G. Holloway
Assistant Director for Administration	Henry R. Hoyt
Assistant Director for Classification and Security	Ralph Carlisle Smith
Assistant Director for Engineering	John Bolton
Assistant Director for Production	Max F. Roy
Assistant Director for Scientific Personnel	William H. Crew

DIR Projects

DIRP. Under direction of Darol K. Froman

Group Leader DIRP-1: L. D. P. King

Group Leader DIRP-2: R. Philip Hammond

The objective of the DIRP project is to design, build, and operate an experimental high-temperature (430°C) and high-pressure (5000 psi) homogeneous reactor of a novel type. Such a system is of fundamental interest from the standpoint of the behavior of aqueous uranium solutions at or near the critical point. It is also of practical interest as a possible replacement for the existing Water Boiler as a neutron source and for the exploration of homogeneous systems for their possibilities with respect to the production of useful power from nuclear fission.

DIRX. Under direction of Marshall G. Holloway

This project was responsible for the coordination and over-all development and production of thermonuclear weapon warheads, including those for the Castle tests (Spring 1954). As of about January 1, 1954, the development activities of DIRX are being transferred to technical committees, while the design of the outer cases of thermonuclear devices and the integration of the components into a complete warhead design is being taken over by the new Group W-6. Production of the warheads will be under the supervision of the Assistant Director for Production. As an element of Task Force Seven, DIRX will remain responsible for the field assembly of the thermonuclear test devices at Castle.

7.4 Technical Division Activities

CMR Division

Division Leader: Eric R. Jette

Alternate Division Leader: Robert D. Fowler

Assistant Division Leader: Robert L. Shehan

CMR Division performs chemical and metallurgical research on fissile materials and other special bomb constituents, such as deuterium and tritium and their compounds. Development and service support are provided in these fields to other divisions of the Laboratory. Nuclear components for prototype weapons and test devices are fabricated in conjunction with the Shop Department, and production methods for fissile and other materials are developed. Production and fabrication procedures originated by CMR Division are available as a starting point when new components are assigned to other AEC contractors for production. Frequently, the first few stockpile units are actually fabricated while a suitable outside facility is being tooled up.

Group CMR-1. Group Leader: Charles F. Metz
Associate Group Leader: Robert T. Phelps
Alternate Group Leader: Herman Ashley

Group CMR-1 provides a general analytical service for the entire Laboratory, although most of its work is performed for other groups in the Division working with fissile materials. A wide variety of techniques are used including alpha- and beta-particle counting, spectroscopy, polarography, coulometry, and petrography. The spectrographic installation is exceptional in many respects. Special microchemical and spectrographic methods have been developed for the analysis of uranium and plutonium, and for traces of a large number of other elements of interest in the weapon field. Because of the expanding activities of the Laboratory, an active research and development section is concerned with the solution of analytical problems arising from the use of new materials.

Group CMR-2. Group Leader: Joe F. Lemons
Alternate Group Leader: Charles E. Holley

The main work of Group CMR-2 is research on the physical and chemical properties of plutonium compounds; in addition, however, it performs inorganic research which is not related to plutonium chemistry. The activities include preparation of compounds and investigation of their structures by magnetic susceptibility, paramagnetic and nuclear magnetic resonance absorption, and Raman spectra. Experiments are made on the physical chemistry of solutions, combustion and solution calorimetry, reaction kinetics, and radiation chemistry.

Group CMR-3. Group Leader: Dwayne T. Vier
Co-Group Leader: Melvin G. Bowman

Prior to the Spring of 1953, the principal task of Group CMR-3 was to fabricate experimental initiators for testing purposes and to provide a token production of new designs of initiators for the stockpile before fabrication could be taken over by an appropriate AEC supplier. This service required a continuous development program and supporting research in polonium

chemistry. As a consequence of this activity the Laboratory can be supplied with a wide variety of neutron sources, using polonium, having strengths up to 10^8 neutrons/sec, and alpha-particle sources up to several curies in strength.

Group CMR-4. Group Leader: Eugene S. Robinson
Alternate Group Leaders: Wesley M. Jones
Robert A. Penneman

Although Group CMR-4 is primarily concerned with research on isotope chemistry, it also performs a substantial amount of service work. The research work includes the preparation and chemical and physical study of compounds of the transuranium elements, neptunium, americium, and curium. Some of the information and techniques are being utilized by J Division in studying bomb residues for radiochemical yield determinations. Research is also being carried out on the chemistry of tritium. As part of its service function, the group purifies tritium, and supplies it to other groups and laboratories as required. Lithium tritide is also prepared by reaction of metallic lithium with tritium. Another section of CMR-4 makes foils of uranium, plutonium, and americium isotopes as well as those containing deuterium and tritium for various Laboratory activities. In addition, it performs many special services usually involving separated or enriched isotopes, e.g., boron-10 for neutron counters containing boron trifluoride.

Group CMR-5. Group Leader: Arthur S. Coffinberry
Alternate Group Leader: Fred W. Schonfeld

The activities of Group CMR-5 are concerned with the metallurgy of plutonium and its alloys. Studies are made of the structure, phase relations, physical and mechanical properties, resistance to corrosion, and ease of fabrication. Because of the health hazard, virtually all equipment is enclosed in dry boxes. Apart from direct application of alloys, e.g., plutonium-gallium, to weapon design, the program is of interest to AEC installations, who call upon CMR-5 for information and service work, particularly in relation to the use of plutonium alloys in breeder reactors.

Group CMR-6. Group Leader: James M. Taub
Alternate Group Leader: Denton T. Doll

CMR-6 is the metal-fabrication group, working in cooperation with the Shop Department; it furnishes fabricated shapes, materials, and services to the Laboratory and to other AEC

projects. The unusual shapes, sizes, and types of materials handled frequently require ingenuity and a novel approach, so that much development work is performed in support of the service activities. The functions of the group are divided into eight sections. The ceramics section forms and fires special refractories and applies enamel and ceramic coatings to metals.

It also operates a plating shop for GMX-7. The fabrication section carries out such operations as sheet rolling, wire drawing, swaging of rods, forging, welding, or deep drawing of various metals, including uranium. The facilities of this section are being increased by the installation of a 5000-ton hydraulic press early in 1954. The general foundry section operates furnaces for the vacuum casting of tuballoy and its alloys, in sizes ranging from about 1 pound to 2 tons. Other nonferrous metals and their alloys are also vacuum cast. The task of the physical metallurgy section is to provide mechanical testing services, e.g., tensile strength, compression, shear, hardness, and impact tests, and metallographic information for the Laboratory. It also acts in a consulting and advisory capacity on general metallurgical problems. Many common plastic materials and techniques are used by the plastics section in filling job orders. Metals, oxides, and other compounds are incorporated into plastics for special purposes and several unusual materials have been coated with plastics. The powder metallurgy section has fabricated into various shapes numerous elements and alloys, especially those which cannot be fabricated by standard methods. With but few exceptions, all oralloy parts used by the Laboratory are made by the oralloy section. These include components for devices tested at the Proving Grounds as well as those used for critical mass and other studies. In addition to vacuum casting of oralloy, foils, sheet, wire, and special shapes are made for experimental purposes. Machining is done in the oralloy machine shop which is part of the oralloy section but is staffed by the Shop Department.

Group CMR-7. Group Leader: James R. Lilienthal

Alternate Group Leader: Charles M. George

The principal functions of Group CMR-7 are to maintain instruments used in CMR Division, especially for radiation monitoring and plant control, to aid members of the Division in instrumentation problems, and to develop new instruments and apparatus for CMR and other Divisions of the Laboratory. These include radiation detection instruments for various purposes, automatic temperature controls, tritium process lines, Raman scanning mechanism, etc.

Group CMR-8. Group Leader: Richard D. Baker

Alternate Group Leader: Ralph W. Kewish

The work of Group CMR-8 is concerned with the chemistry of uranium and falls into two

broad classes, namely, (a) research and development, and (b) production. In addition to performing fundamental research in uranium chemistry, attention is given to the development and engineering of new methods and to the improvement of existing methods for the purification and recovery of uranium from a wide variety of residues. The production program involves the recovery and purification of oralloy residues originating in the Laboratory, the recovery and purification of uranium-233, and the preparation of normal and enriched uranium alloys.

Group CMR-9. Group Leader: Edward F. Hammel, Jr.
Associate Group Leader: Adam F. Schuch

Group CMR-9 is a research group whose primary interest is in cryogenics, i.e., the properties of matter at very low temperatures; for this purpose excellent equipment is available for work in the range from 20°K to below 1°K. Studies are made of the properties of liquid and solid hydrogen isotopes and of liquid helium isotopes. In addition, one section of the group is making equation-of-state measurements with gases at high pressures, e.g., tritium up to 2000 atm. The section provides a consulting service to the Laboratory on high-pressure problems.

Group CMR-10. Group Leader: R. Philip Hammond
Alternate Group Leader: John W. Schulte

The main activity of Group CMR-10 is the preparation of kilocurie sources of radiolanthanum for use in the RaLa experiment by Group GMX-5 and sources of lower strength, from 10 millicuries to 100 curies, for other purposes. A remote-control facility for separating the lanthanum-140 from its parent, barium-140, is operated by the group, and a research and development program is carried out to improve separation methods and to anticipate a variety of demands. The facilities are frequently used to repack or combine strong gamma-ray sources for other Laboratory groups. The responsibility for maintaining the uranyl nitrate solution in the Water Boiler, operated by Group P-2, at an acceptable pH and uranium concentration has been assigned to CMR-10. This has led to an active interest in radiation chemistry, aerosol removal, and isotope-exchange reactions.

Group CMR-11. Group Leader: Richard D. Baker
Alternate Group Leader: Wayne C. Hazen

This group was originally established as a production facility for plutonium weapon components, starting with Hanford nitrate solution and ending with the nickel-coated, finished plutonium hemispheres. However, since the establishment of other AEC production facilities, this aspect of the work of Group CMR-11 has been reduced essentially to stand-by status. Consequently, the group now devotes itself to research and development in connection with fabrication of plutonium and its alloys into various shapes and with the recovery and purification of

plutonium from residues and wastes. Such work is in progress on plutonium casting, with emphasis on precision die-casting for possible use in the production of thin sections of the metal. Special problems have required the preparation of plutonium metal of high purity and of particular compounds. A remote-control plant for the production of metal from plutonium nitrate solution has been built and operated, and research has been carried out on the chemical reactions involved in the many steps of this process. The group is also concerned with a detailed study of nickel carbonyl and the decomposition reaction used for coating various bomb components with nickel.

Group CMR-13. Group Leader: Robert B. Gibney

Group CMR-13 was organized in January 1953 to do metallurgical research in metals, other than plutonium, of interest to the Laboratory. Its activities include a study of the effect of heat treatment on the low-temperature properties of uranium-molybdenum alloys, and the development of a "stainless" uranium alloy. The latter will be prepared and its mechanical properties studied by the group, but the corrosion characteristics will be evaluated by CMR-5. In cooperation with GMX Division, the high-speed loading of metals will be investigated to determine whether phase transitions occur during implosion.

D Division

Division Leader: Ralph Carlisle Smith

Alternate Division Leader: Philip F. Belcher

The Documentary (D) Division handles substantially all written matter of a scientific nature other than stockpile information on weapons and SF (source and fissionable) materials. It is a control point for such matter, in addition to being the source of many technical writings. While D Division is divided into groups, the scientific personnel, in particular, serve in several capacities which cut across group lines. The primary functions of the Division include patents and inventions, classification, declassification, security liaison, editorial and technical information, and summary reports and publications.

Patents and Inventions: All technical reports and publications of the Laboratory are reviewed by scientific and engineering members of the Division for possible inventions to be protected by the Government. The Division reports such inventions directly to the AEC, Washington, D. C., and when requested prepares, secures execution of, and prosecutes patent applications on them.

Classification: All technical and much other outgoing mail from the Laboratory is reviewed by D Division to make certain that the scientific information contained therein is correctly classified. This centralized review enables the Laboratory to maintain a uniform

classification policy. The Division provides the Executive Secretary for the Santa Fe Operations Classification Board and the Los Alamos Field Office Classification Board, which render classification decisions on all aspects of the weapons development and weapons test programs of the AEC. The leader of D Division usually serves as the AEC classification representative in Joint Task Force and continental test organizations in order to maintain this uniformity of classification policy.

Declassification: Within the Division there is a small group which handles declassification of various technical developments and the associated papers originating in the Laboratory. Although responsible reviewers are available throughout the Laboratory and at Sandia, much of the declassification and review is performed by scientific members of D Division.

Security: Security liaison with the AEC and the FBI is maintained through D Division.

Editorial Services and Technical Information: All activities relating to scientific and technical reports within the Laboratory and to the AEC's weapons test organization are administered. Reports received in draft form are given technical editing and prepared for reproduction. The Division also prepares the weekly LASL Bulletin. Requests for information directed to the Laboratory from outside the AEC and contractor organizations are forwarded to the Division for handling directly or for transfer to the SFO Information Office or other appropriate organization.

Libraries: The Division operates the Report Library, where classified reports from the AEC and its contractors and from other sources, especially the Department of Defense, are controlled and disseminated, with the detailed inventory procedure prescribed by AEC regulations. In addition, the Division operates and controls the technical library of the Laboratory and the library at the Health Research Laboratory, that also serves the Los Alamos Medical Center.

Summary Reports and Publications: The Coordinating Organization Director for Military Utilization Projects of the AEC is the Director of the Laboratory, and his executive representative is the leader of D Division. The responsibility for summary and survey technical reports resides in the Director, but in many cases the responsibility for preparing such reports is transferred to the Division. Various books, written by present and former members of the Laboratory personnel, have been prepared under the direction of the Division. Such books and reports have appeared in the National Nuclear Energy Series, have been published by the GPO, or have been issued by the Laboratory.

The Technical Illustration section of D Division prepares drawings and sketches for reports and also the more complex multicolor illustrations and exploded views necessary for briefings of the Joint Chiefs of Staff, and members of the AEC, Joint Task Force, and continental test organizations. A museum, in which the history and development of atomic weapons

will be illustrated, is being established in the old ice house of the former Los Alamos School.

Group Functions: As indicated previously, the scientific personnel in D Division serve in several different capacities, so that there is no precise group organization. However, four groups are at present in existence and their functions are indicated briefly below.

Group D-1. Group Leader: Ralph Carlisle Smith

Alternate Group Leader: William R. Spensley

Group D-1 is concerned with the review of inventions and the preparation of patent applications of such as may warrant protection.

Group D-2. Group Leader: Helen F. Redman

Alternate Group Leader: Elbert E. Steele

The library activities of the Division, including the Report Library, the Technical Library, and the Health Research Laboratory Library are under the control of Group D-2.

Group D-6. Group Leader: Leslie M. Redman

This group is concerned with matter related both to classification and declassification of mail, technical developments, and reports.

Group D-7. Group Leader: David M. Stearns

Group D-7 is responsible for editorial services and technical information, and for the preparation of the weekly Laboratory Bulletin. The Technical Illustration section and the Museum are also part of Group D-7.

GMX Division

Division Leader: Duncan P. MacDougall

Alternate Division Leader: Eugene Eyster

GMX Division has two principal and related missions. These are, first, to carry out research, development, and engineering for production on the firing and HE systems of implosion devices; and, second, to study experimentally the behavior of implosion systems, without fissile material, during and subsequent to the detonation of the high explosive. The work includes the design and testing of X-units, detonators, implosion lenses, and HE inner charges, and studies of the symmetry and other properties of the shock waves accompanying an implosion.

Group GMX-1. Group Leader: Gerold H. Tenney

Alternate Group Leader: James W. Dutli

All nondestructive testing and inspection, which is largely radiographic in character, is performed for the Laboratory by Group GMX-1. For this purpose use is made of X-ray machines with peak voltages up to 1000 kv, a 22-Mev betatron, and various gamma-ray sources,

including radium and cobalt-60. Several commercially available inspection tools, such as Magnaflux and Reflectoscope, and others that have been specially developed, are used in non-destructive tests not involving radiations. This group is part of GMX Division primarily for historical reasons; the first radiographic inspections made at Los Alamos were carried out on HE charges.

Group GMX-2. Group Leader: Louis C. Smith

Group GMX-2 carries out research, testing, and early development on high-explosive materials. In addition to a laboratory, in which small-scale chemical work can be performed, the group has a number of processing buildings and an environmental test chamber in which a wide variety of climatic conditions and changes can be simulated. Explosive materials of interest, which cannot be purchased commercially, are synthesized by an organic chemistry section. The group has a special interest in the development of plastic bonded explosives for various purposes.

Group GMX-3. Group Leader: Melvin L. Brooks

This is the largest group in GMX Division and it is concerned essentially with the HE systems for implosion bombs. Group GMX-3 designs, develops, and engineers for production the HE lenses and inner charges for these weapons and also the HE systems required for special experiments. Research and development is carried out on the techniques of fabrication of lenses and inner charges, and all HE charges and systems used in the Laboratory are made by GMX-3. In addition, the group writes product specifications for all HE systems fabricated in AEC plants, assists these plants to get into production on new designs, and provides support to the AEC on day-to-day acceptance of finished items. Facilities are available for casting, machining, inspecting (radiographic and dimensional), and assembling HE systems. The group also operates a large magazine area.

Group GMX-4. Group Leader: Eric L. Peterson

Alternate Group Leader: Frederick Tesche

The primary activity of Group GMX-4 is to study the behavior of imploding systems by the pin technique. For this purpose, a number of firing points are operated; with each point is an instrument (or recording) chamber containing a large number of oscilloscopes and similar devices. Measurements of tamper velocity and symmetry, and of shock velocity and symmetry in the pusher, tamper, and ball, made by the pin method, constitute an important stage in the development of new implosion systems. In addition to these implosion studies, research is carried out on shock waves and equations of state, using the same basic technique and equipment.

Group GMX-5. Group Leader: Donald Mueller

Alternate Group Leader: George H. Best

The functions of Group GMX-5 are mainly concerned with a study of motions and, especially, compressions occurring in the metal components of an implosion system by the RaLa method. The scintillation detectors for gamma rays and the fast amplifiers now available give an over-all response time of about 0.01 μsec.

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Because the equipment and techniques are particularly applicable, GMX-5 has been devoting a large portion of its effort to studies of the behavior of thermonuclear initiators.

Group GMX-6. Group Leader: Frank J. Willig

Alternate Group Leader: Frank A. Lucy

Group GMX-6 utilizes high-speed photographic equipment, including both motion-picture type and streak cameras, to observe the behavior of imploding systems and of mock-ups of various features of such systems. The group also makes use of photographic technique for fundamental studies of shock waves and equations of state. While GMX-6 has some electronic timing and control equipment, the bulk of its observations are made by the cameras referred to above.

Group GMX-7. Group Leader: R. L. Spaulding

Alternate Group Leader: A. D. Van Vessem

This group does research and development on firing systems for implosion weapons, including both X-units and detonators. For detonators, GMX-7 carries the project all the way from early design studies, through development and engineering for production. It usually does some early production for stockpile in addition. Most of the detonators are now made elsewhere, but the group still supplies specifications, procedures, and gives any assistance that may be required.

At present all detonators for the AEC are accepted by Group GMX-7, but it is expected that the responsibility for routine acceptance will soon be taken over by AEC staff, with the group providing support in the form of advice and occasional spot checking. Although GMX-7 does research and development on X-units, the engineering, production, and surveillance are not done by the Laboratory. However, final X-unit designs are in all cases certified by the group with respect to their ability to fire detonators properly.

Group GMX-8. Group Leader: Arthur W. Campbell

Alternate Group Leader: Charles W. Mautz

The test firing of lenses and of other HE charges is performed by Group GMX-8. For

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this purpose a number of individual firing points are operated. Each point has a protected shelter, which houses the rotating mirror (streak) camera and electronic equipment, and a firing mound upon which charges up to a thousand pounds of HE can be safely fired. Some of the work of GMX-8 is done as part of the development program on new lens systems, and the remainder of its service function consists of firing, on a sampling basis, of lenses which are in routine production by GMX-3. The two primary quantities measured are the transit time and the trace spread. The transit time, i.e., the time required for the detonation wave to pass through the lens, is measured by timing the interval between the closing of two electrical circuits. The trace spread, which is a measure of the failure of the detonation wave to emerge simultaneously at all points across the lens face, is determined by a streak camera. GMX-8 also uses the same equipment to perform fundamental studies on various properties of detonating HE material, such as detonation velocity, detonation zone structure, etc.

Group GMX-9. Group Leader: Berlyn Brixner

The work of GMX-9 is to develop new and improved types of cameras for the entire Laboratory; it also operates a stock room of optical and photographic equipment and accessories of unconventional design. High-speed streak cameras and ultra-high-speed frame cameras, having frame rates from 5×10^4 to 3.5×10^6 frames/sec, have been developed. The group is also concerned with cameras for oscilloscopes and similar instruments. The design and fabrication of turbine drives for the high-speed cameras is performed by GMX-9, and prescriptions are developed for entirely new lens systems where no available lens will satisfy the special requirements.

H Division

Division Leader: Thomas L. Shipman, M. D.

Alternate Division Leader: Harry O. Whipple, M. D.

The essential purpose of the Health (H) Division is to protect and maintain the health of all Laboratory employees. In addition to providing the usual industrial medical and safety services, the Division is responsible for the supervision of radiological safety activities, including radiation monitoring. Because of the unusual nature of the problems arising from operations involving plutonium, polonium, and other radioactive materials, the Division carries out appropriate biomedical research. The organization of the health services for the Laboratory differs somewhat from that in most AEC installations and industrial groups in the respect that all such services are grouped into a single organization with Division status.

The work of H Division may be divided broadly into two categories. Groups H-1, H-2, H-3, and H-5 are essentially health and safety service groups having both preventive and

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remedial functions. Since the members of these groups frequently encounter special problems which they are not prepared to solve alone, there are two additional Groups, H-4 and H-6, for research and development. Although much of the work of these two groups is concerned with problems of immediate interest to the Laboratory, a considerable amount of fundamental research, bearing on the over-all weapons program, is carried out in the fields of biophysics, biology, and medicine. In spite of the group structure of H Division, it is seldom that any problem arises that can be handled entirely by members of any one group. There is thus considerable co-operation among the groups, and on occasion the facilities of all six groups may be devoted to a single problem.

Group H-1. Group Leader: Dean D. Meyer

Alternate Group Leader: Leo G. Chelius

Group H-1, which is the largest group in the Division, is responsible for radiation monitoring. Although in certain parts of the Laboratory monitoring may be done on a more or less routine basis, it is still necessary to have a group of experienced monitors who are ready for all eventualities. The members of the group are thus prepared to do alpha-particle monitoring, beta-gamma monitoring, neutron hazard evaluation, and personnel decontamination. One section of Group H-1 supervises all equipment decontamination, while another is in charge of film badges and photodosimetry for the entire Laboratory.

Group H-2. Group Leader: Robert S. Grier, M. D.

This is the occupational health group, frequently referred to as the industrial medicine group. It is staffed by three physicians and seven nurses, who, with various assistants, provide the services offered by the medical department in any large industry. Group H-2 performs pre-employment and termination physical examinations and any other examinations that may be necessitated by routine or occupational requirements. The group renders the customary first-aid for minor injuries and illnesses, and institutes investigations where working conditions may be questioned. In view of the unusual nature of the Laboratory activities, special studies, frequently requiring a certain amount of clinical research, are underway most of the time. Problems of this kind frequently involve co-operation among this group and the monitoring (H-1), safety (H-3), and industrial hygiene (H-5) groups. The physicians on the staff of H-2 are available at all times to any employee who may desire medical advice.

Group H-3. Group Leader: Roy Reider

Group H-3 is small, consisting of the group leader and three assistant safety engineers who fulfill the functions commonly performed by safety engineering groups in industry. In the Laboratory, however, a wide variety of problems of an unusual character are encountered. Members of the group must be familiar with the transportation, storing, and handling of

explosives, and they must also be well grounded in matters relating to both temperatures and pressures that may be extremely high or extremely low. They must also be well informed in connection with traffic safety and fire prevention.

Group H-4. Group Leader: Wright H. Langham

Biomedical research is the primary function of Group H-4, which is divided into four sections, dealing with biochemistry, radiobiology, radiopathology, and organic chemistry, respectively. Most of the work of this group is composed of relatively short-term studies on problems of direct or indirect interest to the Laboratory. In addition, there are a number of long-range research programs of a more or less basic nature.

Group H-5. Group Leader: Harry F. Schulte

Alternate Group Leader: Edwin C. Hyatt

The work of Group H-5 is concerned with industrial hygiene; its general function is similar to that of Group H-1, although it deals primarily with toxic rather than radiation hazards. The field section of this group carries on a continuous program of air sampling and other studies, wherever called for in and around various shops and laboratories. The air samples may be examined for relatively common industrial poisons, such as lead, mercury, carbon tetrachloride, benzene, etc., but in addition techniques must frequently be devised for the large number of potential poisons which are often unique to the Laboratory operations. Among their other responsibilities, the engineers of H-5 must be prepared to approve or disapprove the adequacy of ventilation hoods and similar laboratory installations. Members of the group are able to advise other Laboratory workers on the best methods for performing unusual tasks which may involve an element of danger. The laboratory section of Group H-5 is responsible for the assay of urine specimens for plutonium; this technique has been found to provide a very reliable index of exposure to the element or its compounds. The members of this section also carry out a wide variety of other analytical procedures, their range of work being considerably more extensive than that required of most State industrial hygiene laboratories. Finally, H-5 has a test operation section which is the outgrowth of the group's very extensive interest in problems connected with the fall-out following test shots at the Nevada Proving Grounds.

Group H-6. Group Leader: Thomas N. White

Meteorological Service: George J. Newgarden, Major, USAF

The radiological physics group, H-6, is composed of three sections, which are responsible for special problems, field test activities, and meteorology, respectively. The special problems section performs research and development primarily designed to support the monitoring work of Group H-1. In addition, members of this section may concern themselves with

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problems of special interest to other groups. The field test section was established to maintain continuity of information concerning safety matters at weapon tests, both in the Nevada and Pacific Proving Grounds. The meteorology section, staffed by members of the Air Weather Service, USAF, not only provides daily weather forecasts for the immediate Los Alamos area, but also supplies technical assistance to any member of the Laboratory with a problem involving meteorology. A considerable amount of time of this section is devoted to matters of primary interest to J Division.

J Division

Division Leader: Alvin C. Graves

Alternate Division Leader: William E. Ogle

Associate Division Leaders: John C. Clark
Roderick W. Spence

The work of J Division is concerned with the general weapons-testing activities of the Laboratory. The Division is responsible for organizing field tests at the Nevada and Pacific Proving Grounds. In addition to the actual detonation of weapons being tested, this work calls for the provision of suitable personnel and equipment to plan and make the wide variety of diagnostic and other measurements associated with weapons tests. The development of special techniques as required by novel circumstances is an important aspect of this work. Finally, the Division acts as a liaison between the Laboratory, the AEC, and military Task Forces that may be involved in the conduct of the tests.

Group J-1. Group Leader: Armand W. Kelly

The functions of Group J-1, which is concerned with personnel and administration, include procurement of military personnel for the Division activities, processing personnel for travel to the Proving Grounds, and general administration for Laboratory personnel taking part in the weapons tests. The group also determines the working space and living quarters required for those participating in the tests and makes the necessary arrangements to meet these requirements.

Group J-3. Group Leader: Duncan Curry, Jr.

Associate Group Leaders: B. Carl Lyon
Philip L. Hooper

Plans and operations are the responsibility of Group J-3, which determines the operational requirements for the scientific programs in full-scale test activities and makes arrangements for facilities, equipment, and other necessary support. Detailed operation plans and orders are prepared, and provision is made for adequate communications and transportation facilities for the test groups at field locations.

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Group J-6. Group Leader: Robert H. Campbell

Alternate Group Leader: Robert W. Newman

This group handles the construction and engineering aspects of field test operations. Its work includes liaison between the test group and the AEC and its contractors, and involves following the progress of the construction through to completion to be sure that the facilities are adequate for the purposes of the test groups. Group J-6 is also responsible for arranging a system of machine-shop facilities at the Proving Grounds for the repair, maintenance, and minor fabrication of equipment for scientific observations.

Group J-7. Group Leader: Theodore J. Blechar

Alternate Group Leader: James H. Hill

Group J-7 provides such engineering services and advice to the experimental groups as may be requested. It establishes design specifications for experimental equipment and makes drawings for shop fabrication, records, reports, etc. Equipment to be fabricated is routed through the machine shops, and items made by the shops or purchased from commercial vendors are checked, tested, and installed before delivery to the experimental groups.

Group J-10. Group Leader: Herman Hoerlin

Alternate Group Leader: Daniel F. Seacord, Jr.

The work of this group, in the field of blast hydrodynamics, is theoretical and analytical and is concerned with hydrodynamic yield, operational effects, and diagnostic experiments. In the determination of absolute yield, Group J-10 utilizes observations of the ball of fire. The calculations involve studies of theoretical wave forms, equations of state, radiative transport, and surface interactions. The responsibility for operational effects is primarily the prediction of blast and thermal effects for test planning. In this connection studies are made of previous test results on blast, damage criteria, water-waves, and propagation of shock waves in an inhomogeneous atmosphere. The purpose of the diagnostic work is to furnish information on the hydrodynamic aspects of experiments done by other groups in the Division.

Group J-10 also studies thermal radiation from the diagnostic, operational, and tactical standpoints. Most of the experimental work is conducted by the Optics Division of the Naval Research Laboratory, with which close liaison is maintained. Measurements are made of the prompt thermal radiation (thermal yield) and of the thermal power as a function of time. This includes studies of the spectral characteristics of the bomb energy in the infrared, visible, and ultraviolet regions. Spectroscopy is applied to determine the time dependent temperature and energy distributions of the radiant surfaces and of the space distribution of bomb components in the fireball. The propagation of radiation through air at normal and high temperatures is investigated, and optically-absorbing reaction products of air constituents formed by nuclear

and thermal radiations are identified. Recently, the study of selected optical problems, such as films for high-speed photography, have been added to the responsibilities of this group.

Group J-11. Group Leader: Roderick W. Spence

Alternate Group Leader: Jere D. Knight

Group J-11 employs the methods of radiochemistry to study yield, efficiency, neutron economy, and other behavior parameters of nuclear tests. Yield and efficiency are obtained from measurements of fission products and fissile elements remaining in airborne and surface debris collected after the explosion. By determining the radioactivity of other elements, such as those present in structural materials, in the environment, or deliberately introduced as "detectors" in or near the test device, information is obtained concerning local and over-all neutron economy and the performance of individual components. In support of this work, research is carried out on the properties of radioactive nuclei, on nuclear reactions, and on the chemistry of radioactive materials. Particular attention is paid to the study of isotopes and reactions obtainable only in the high neutron fluxes and temperatures of the interior of an exploding nuclear device.

Group J-12. Acting Group Leader: Leon J. Brown

Alternate Group Leader: Donald D. Phillips

Neutron flux measurements are made by Group J-12 on both fission and thermonuclear devices. The external neutron flux data contribute information concerning the total neutron economy and, in boosted and thermonuclear systems, make possible calculation of the total thermonuclear burning. b(3) [redacted] Measurements of high-energy (10 Mev or above) gamma-ray intensities associated with nuclear explosions add to the knowledge of neutron economy. Appropriate laboratory research is performed in support of this program, which involves the use of threshold detectors for (n,γ), (n,p), $(n,2n)$, and (γ,n) reactions, of nuclear emulsion plates, and of photocell-phosphor combinations for time studies.

Group J-13. Group Leader: Newell H. Smith

Alternate Group Leader: John S. Malik

This group studies fission-reaction history by determination of the neutron-multiplication rate (α) during the early stages of the explosion; this involves measurement of the intensity of prompt gamma rays which increases at the same rate as the neutron population. More efficient and more economical methods for determining the multiplication rate are being developed.

Group J-15. Group Leader: Gaelen L. Felt

Diagnostic and other tests by optical methods represent the prime function of Group J-15.

Diagnostic experiments for full-scale tests, utilizing optical, e.g., high-speed photographic, techniques, apart from spectroscopic, are designed to provide information concerning radiative and hydrodynamic behavior of nuclear devices in the stages immediately following the detonation. Non-diagnostic experiments, using exploding devices as sources, are also planned for research chiefly into various aspects of radiation hydrodynamics. The group designs and tests assemblies and instrumentation systems for carrying out these experiments. The field phase of the work is planned and executed and the data obtained are analyzed, reduced, and reported in suitable form. Liaison is maintained with outside contractors doing photographic work for the Laboratory in connection with weapons tests, and this work is subjected to general supervision.

Group J-16. Group Leader: Bob E. Watt

The primary responsibility of Group J-16 is the study of the reaction history in thermonuclear experiments. In general, the observations are made on the emission of neutrons and gamma rays, often in collimated systems, in order to determine the locality and efficiency of the thermonuclear burning. Gamma-ray intensity measurements as a function of time are made up to a period of seconds; these measurements may be applied to independent determinations of thermonuclear and fission yields. Other phenomena are being investigated, e.g., electromagnetic signals, for the purpose of developing new techniques which are either simpler than those now in use or which are adapted to special cases, such as operational or air drops. Basic cross section and diffusion calculations required for the interpretation of neutron and gamma-ray signals from thermonuclear devices are an important aspect of the work done. Radiation detection instruments which satisfy the special requirements of field work, namely, high time-resolution combined with improved sensitivity as compared with those available commercially, are being developed.

P Division

Division Leader: J. M. B. Kellogg

Alternate Division Leader: Richard F. Taschek

The activities of P (Physics) Division fall into two more or less distinct parts. One part, involving somewhat less than half of the total personnel, is devoted to the design and construction of a wide variety of electronic equipment for use in many Laboratory activities. The second part is concerned with problems of basic experimental physics and includes measurement of neutron cross sections for various processes, charged-particle reactions, fission physics, beta-ray spectroscopy, particle-counter development, and the investigation of controlled thermonuclear reactions. In general, many of the activities of P Division are dictated by the over-all interests of the Laboratory.

Group P-1. Group Leader: John K. Lamb

Alternate Group Leader: Richard J. Watts

Group P-1 designs and constructs electronic equipment, mainly at the request of other Laboratory groups but sometimes to anticipate a possible future demand. Maintenance and repair service is provided for various electronic instruments including those used for health monitoring. The group procures or makes much standard Laboratory equipment, including power supplies, pressure and vacuum controls, amplifiers, scalers, pulsers, and pulse-height analyzers. An electrical standards laboratory is maintained where checks can be made against standardized units of inductance, capacitance, resistance, and emf. There is also a clock, accurate to one part in 10^8, and facilities for determining frequencies.

Group P-2. Group Leader: Carroll W. Zabel

The enriched, homogeneous nuclear reactor, known as the Water Boiler, is operated by this group; the usual operating power is 25 kw. The maximum thermal neutron flux, in a reentrant tube 1 inch in diameter through the center of the reactor sphere, called the "glory hole," is 10^{12} neutrons/cm^2-sec. In addition, there is an appreciable flux of fast neutrons. The fast-neutron reactor, known as Clementine, has been dismantled and a new thermal reactor, with a power of 1000 to 2000 kw, is being planned. With the aid of the Water Boiler, experimental work is done on the fission process, e.g., angular correlation of fission fragments, velocity distribution of slowed fission fragments, and energy of fission fragments. Some studies are being made of radioactive nuclei, mainly, but not exclusively, of fission products. A uranium-235 "converter," used with the Water Boiler, provides a fission spectrum of neutrons, and with these a number of total neutron cross sections have been measured as a function of energy in the range from 7 to 12 Mev. Determinations are also made of the average fission cross section of uranium-238 for fission spectrum neutrons, and inelastic scattering cross sections for many elements, including fissile species. Group P-2 provides neutron irradiation services to the Laboratory and, to a limited extent, to other AEC contractors.

Group P-3. Group Leader: Richard F. Taschek

Alternate Group Leader: Arthur Hemmendinger

This group operates two electrostatic (Van de Graaff) accelerators, both providing a maximum potential difference of 2.5 Mv. These are used for the investigation of light-particle reactions; yields and cross sections for these reactions, and angular distributions and energies of the particles produced are measured. The interaction of neutrons with light elements (thermonuclear) and heavy elements (fission) and with other elements are studied. With the latter, the (n,2n) reactions are of special interest for radiochemical studies in weapons tests. Group P-3 makes precision measurements of fission cross section and of the number of neutrons released in fission as functions of neutron energy for high-energy neutrons.

Groups P-4 and P-6. Group Leaders: James H. Coon
Elizabeth R. Graves

These groups work mostly with 14-Mev neutrons produced by the bombardment of tritium, in a zirconium target, with deuterons accelerated by a 250-kv Cockcroft-Walton apparatus. The interactions of these neutrons with various thermonuclear fuels, possible tamper materials, and fissile materials are of special interest. Among the investigations being made with 14-Mev neutrons are the following: study of gamma rays produced by bombardment of various substances; inelastic and elastic scattering; total cross sections of elements; number of neutrons produced in fission; neutron multiplication; cross sections for (n,2n) reactions; and cross sections for the production of unwanted particles in their interaction with lithium nuclei. Group P-4 also calibrates neutron sources, using a standard graphite "pile." A Cockcroft-Walton accelerator, with a potential difference of 600 kv, is under construction.

Group P-7. Group Leader: James L. Tuck

By means of a 250-kv Cockcroft-Walton accelerator, Group P-7 is studying charged-particle reactions at relatively low energies, equivalent to those of interest for thermonuclear processes. Precision measurements of the cross sections for the D-D and D-T reactions at low energies have been made in this manner. The group is also devoting attention to the "Perhapsatron," which is a device whereby a controlled thermonuclear reaction may perhaps be initiated by using the "pinch effect," i.e., by the magnetic self-constriction of a high current discharge.

Group P-8. Group Leader: Clyde L. Cowan, Jr.

The main objective of Group P-8 is the construction and operation of very large liquid or plastic scintillation counters. The present specific application of such counters is to the hope of detecting the free neutrino as a result of its interaction with a proton to produce a neutron and a positron. Because of the extremely low cross section for this reaction, it could be observed only by means of a large counting device. One form of the device, already in operation, has been used to measure the total radioactivity of the human body.

Group P-9. Group Leader: Joseph L. McKibben

Group P-9 is occupied with the construction, operation, and use of a large electrostatic (Van de Graaff) accelerator having a potential difference of 10 Mv. This is necessary to provide monoenergetic neutrons in the energy range from 6 to 14 Mev which is acquiring special significance in connection with thermonuclear devices. Hitherto, the accelerator has been operated up to a potential of 5 Mv. High-energy neutrons are used mainly for the measurement of fast-neutron cross sections of thermonuclear and fissile materials.

Group P-10. Group Leader: Louis Rosen

This group, which has no facilities other than nuclear-plate cameras and plate-reading

facilities, uses the nuclear photo-plate technique to study the interaction of neutrons with various materials. Observations are made in this way of the neutron spectrum from a multiplying assembly bombarded by high-energy neutrons; of charged particles resulting from the reaction of 14-Mev neutrons with the isotopes of lithium; of cross sections for deuteron disintegration in the D-T and D-He^3 interactions. Group P-10 reads the fast-neutron health (film) badges for the Laboratory. It has also done some work on Taylor instability.

Group P-12. Acting Group Leader: Keith Boyer

Group P-12 operates and uses the cyclotron which gives deuterons of about 11-Mev energy. This accelerator is to be rebuilt, so that it can go to higher energies and also be capable of accelerating a number of other ions. The main work at present is concerned with (n,2n) cross sections of uranium-238 and the fission cross section of uranium-239. The latter problem is related to the yield of thermonuclear devices as affected by the fission of uranium-239 formed by neutron capture in uranium-238. A long series of experiments of (d,p) and (t,p) processes with fissile materials is involved.

T Division

Division Leader: J. Carson Mark

Associate Division Leaders: Frank C. Hoyt
Robert D. Richtmyer

In general, the Theoretical (T) Division is engaged in applying the methods of theoretical and mathematical physics and mathematics to various problems of the Laboratory and in developing methods to deal with new problems as they arise in the weapon design field. Thus, a major part of the attention of the Division is directed at attempts to understand the effects of various factors in weapon behavior, to predict the behavior of weapon systems, and to propose new systems of interest. As a rule, a basically new scheme for a nuclear weapon is first called to attention within T Division and receives its preliminary consideration there. In addition to this primary function, and in a large measure as a basis for it, the Division engages in a wide range of theoretical studies, including analysis of experiments, nuclear cross section theory, nuclear reactor theory, equation-of-state theory, neutron diffusion theory, hydrodynamics, and techniques of numerical computation.

Because of the special nature and variety of T Division activities, it is not possible to describe its functions completely according to its group organization. The major part of the work of the Division is accomplished by individuals applying their own particular training and experience, in one or more of the fields of study mentioned above, to problems related to fission weapons, thermonuclear weapons, the needs of other Divisions of the Laboratory, or necessary basic research. There are, however, two functions which have required the efforts

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of groups of persons to handle them and to provide the necessary continuity of effort. These are, first, the very extensive numerical computations that have been made in connection with the problems of nuclear weapon design and behavior which are handled by Groups T-1 and T-7; and, second, the theoretical aspects of weapon design, which are the responsibility of Groups T-4 and T-5.

Group T-1. Group Leader: Bengt Carlson
Alternate Group Leader: Max Goldstein

Group T-1 provides a general computing service to the Division and other parts of the Laboratory. Use is made of a variety of computing equipment, ranging from desk calculators, through the standard IBM multipliers, tabulators, etc., to the IBM 701 calculator, which is one of the most recent, fast, electronic computing machines.

Group T-2. Group Leader: Frederick Reines

Group T-3. Group Leader: Rolf Landshoff
Alternate Group Leader: G. Foster Evans

Group T-4. Group Leader: Conrad L. Longmire

This group has given special attention to problems arising in the field of neutron diffusion theory, particularly as applied to calculations of efficiency and yield of actual or possible weapon designs. It is also engaged in a wide variety of other activities in the field of nuclear weapons.

Group T-5. Group Leader: George N. White, Jr.
Associate Group Leader: Harwood G. Kolsky

In addition to a number of activities in the field of applied mathematics, Group T-5 has given special attention to the implosion problem. Several hundred implosion calculations have been performed, making use of the equipment of T-1 for this purpose.

Group T-6. Group Leader: Harris Mayer

Group T-7. Group Leader: Nicholas Metropolis

Group T-7 has designed and built at the Laboratory a fully automatic electronic calculator, known as the MANIAC, which has been in operation since the Spring of 1952. At that time, it was one of the most advanced pieces of equipment of this kind in operation anywhere in the United States. The group provides a general computing service for the Laboratory on the MANIAC. It also investigates computing techniques and moves to take advantage of new developments and improvements in electronic computer design.

Group T-8. Group Leader: Stanislaw Ulam

Group T-9. Group Leader: Bergen Suydam

Group T-10. Group Leader: Louis Goldstein

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W Division

Division Leader: Raemer E. Schreiber

Alternate Division Leader: David B. Hall

Assistant Division Leader: Benjamin L. Moore

The work of W (Weapons) Division is devoted mainly to weapon development. The Division participates in the exploration of the nuclear aspects of new weapon designs and has the basic responsibility for carrying the engineering of these designs through the development, testing, and production stages. Although this function of W Division applies essentially to the atomic warhead, some of its programs include joint responsibility with other organizations for over-all design of new weapons. The Division is also responsible for the acceptance and assembly procedures for nuclear components and for the development of field and laboratory equipment for stockpiling and inspecting active material. In connection with this activity, appropriate instructional and training manuals are provided for the Armed Forces.

Group W-1. Group Leader: George B. Sabine

Alternate Group Leader: W. W. Carter

b(3)

[redacted] The engineering functions include the design of experimental components, mechanical and environmental testing, preparation of special components for nuclear tests, and the development of detailed designs and specifications for the production of nuclear components which are stockpiled. The preparation and loading of nuclear materials for tests at the Nevada and Pacific Proving Grounds are the responsibility of the group.

Among the development activities are the origination and specification of handling, storage, and inspection procedures for nuclear components, e.g., design and prototype procurement of handling tools and inspection gauges. The manuals and military liaison section prepares and issues instructions for the handling of stockpile nuclear material. Research and development is carried out in allied fields, such as isotopic analysis of heavy elements, neutron-counting techniques, and methods for determining the enrichment of oralloy.

Group W-2. Group Leader: Hugh Paxton

Alternate Group Leader: John D. Orndoff

The main activity of Group W-2 is concerned with experiments on chain-reacting systems. It operates the remote-control laboratory for studies of critical and near-critical assemblies. Research is performed on the detailed behavior of chain-reacting systems, including the effect of small amounts of "poisons" on a critical assembly and the interpretation of the results in

terms of neutron cross sections. Critical mass determinations are made with a wide variety of systems, both for the purpose of studying their fundamental behavior and to provide information concerning the nuclear safety of weapon configurations or of manufacturing processes involving fissile materials. Members of the group act as consultants on nuclear safety to the Laboratory and to associated AEC contractors.

Group W-3. Group Leader: Donald MacMillan

Alternate Group Leader: Harlow Russ

The responsibilities of Group W-3 fall into two somewhat distinct categories. In the first place, it is responsible for essentially all gun-type weapon development work carried out by the Laboratory. b(3)

[redacted] A detailed treatment of some aspects of the work of this group is given near the end of Chapter 5.

Group W-4. Group Leader: Arthur Sayer

Alternate Group Leader: Robert K. Osborne

Group W-4 acts as a liaison between the theoretical and experimental work on fission weapons. Estimates are made of the influence on the expected yield of changes in the various parameters at the disposal of the warhead designer; among these are diameter of the HE system; diameter and mass of the tamper; and mass, composition, and geometrical arrangement of the fissile material. By means of calculation and empirical procedures, proposals are made for the optimum (or near-optimum) design for a specific weapon application. The group is also concerned with practical problems of weapon fabrication in evaluating the effect on yield of departures from ideal geometry of actual weapon designs.

Group W-5. Group Leader: Vernal Josephson

Alternate Group Leader: John R. Wieneke

Group W-5 has two unrelated functions. In the field of external initiation, it has developed the betatron (PRM) and pulsed D-T (ENS) initiators, and has conducted tests at the Nevada Proving Grounds which utilized the former device. In connection with thermonuclear weapon development, the group has the responsibility for the flight and drop testing, and for the organization and early conduct of the weapon assembly operations required under the Emergency Capability concept.

Group W-6. Group Leader: George M. Grover

Alternate Group Leader: Jacob J. Wechsler

Certain aspects of the work in the two-stage, thermonuclear weapon field, formerly conducted by the DIRX staff, is being taken over by Group W-6 as of January 1, 1954. The group will be responsible for the design of the outer case of the devices and for the integration of component designs into that of a complete warhead.

7.5 Administrative and Service Departments and Groups

Accounting Department. Head: A. Dwight Richardson

Keeps financial records and accounts of Laboratory operations.

ADP-SF Group. Group Leader: Glenn R. Champion

Maintains SF (Source and Fissionable) material accountability for the Laboratory.

Budget Office. Head: Leslie G. Hawkins

Prepares the budget for the Laboratory.

Business Office. Manager: Albert E. Dyhre

Maintains liaison on contracts with AEC and subcontractors; makes arrangements for travel and workmen's compensation.

Engineering Department. Head: John Bolton

Provides construction and maintenance engineering services for the entire Laboratory.

Graphic Arts Group. Group Leader: Loris Gardner

Functions include photography at the Laboratory and in connection with weapons tests; photostat, Ozalid, and litho reproduction; assembly and binding.

Mail and Records Group. Group Leader: Pat McAndrew

Alternate Group Leader: Blanche Gilman

Collects and distributes mail and other correspondence and keeps records with special attention to classified matter.

Personnel Department. Head: John V. Young

Performs customary personnel functions.

Shop Department. Head: Gus H. Schultz

Operates all professionally staffed machine shops for the Laboratory.

Supply and Property Department. Head: Harry S. Allen

Procures, stores, issues, and keeps account of all supplies and property; responsible for shipping and receiving.

Wage and Salary Department. Head: John A. Woodward

Performs customary wage and salary functions.

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LOS ALAMOS SCIENTIFIC LABORATORY
of the
UNIVERSITY OF CALIFORNIA

Report written:
January 1954

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By Donald P Dickason / Jim Dominici
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WEAPONS ACTIVITIES
of
LOS ALAMOS SCIENTIFIC LABORATORY
PART II (U)

by

Samuel Glasstone

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Chapter 8

Thermonuclear Devices

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8.1 Introduction

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Thermonuclear Burning

As seen in the preceding chapters, thermonuclear (D-D and D-T) reactions are used for the initiation and the boosting of nuclear fission chains.

The problem to be considered in this chapter is the development of methods whereby large amounts of energy may be produced from thermonuclear reactions.

The continuous release of energy in a thermonuclear system involves the propagation of a chain reaction; but this resembles a thermal chain, such as occurs in flame propagation, rather than a fission chain. In the latter, particles, i.e., neutrons, produced in one step of the reaction are the means for causing further (fission) reaction to occur. In a thermonuclear system, as in a flame, the energy liberated in the reaction raises a volume element to a high temperature. This heats an adjacent volume element sufficiently to permit the reaction to occur rapidly. The resulting increase of temperature then heats a further volume element, and so on, until the reaction (or flame) has spread throughout the whole system. It is this similarity between thermonuclear reactions and flame propagation that gives rise to the use of the term "burning" in the former case (see Section 1.6), as in the latter.

It should be noted that whether burning, i.e., propagation of the reactions, will occur or not, depends on a competition between the rate at which heat is produced by the reactions and that at which it is lost, from a given volume element, in various ways. The former must, of course, predominate if burning is to occur, and the temperature attained must be high enough for the reactions to be rapid.

Material and Radiation Energies

At temperatures of the order of a few thousand degrees, the energy of a system is almost entirely material energy, i.e., essentially thermal kinetic energy with perhaps a small amount of potential energy. This material energy, E_m, is proportional, approximately, to the mass, M, of the system and to its absolute temperature, T; thus,

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$$E_m = aMT \,, \qquad (8.1)$$

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where a may, for the present purpose, be regarded as constant for the given system.

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8.2 Thermonuclear Reaction Rates

Barrier Penetration

In order for two nuclei to react, they must approach sufficiently near to one another to permit the short-range nuclear (attractive) forces to become effective. This approach will be prevented by the electrostatic (coulomb) repulsion between the positively charged nuclei. In other words, there is a potential barrier which must be overcome before the nuclei are close enough to interact. If r is the distance between the nuclei, then the height of the barrier at this point is equal to the coulombic energy, $ZZ'e^2/r$; Z and Z' are the respective nuclear

*For the basis of expressing absolute temperatures in energy (kev) units, see below.

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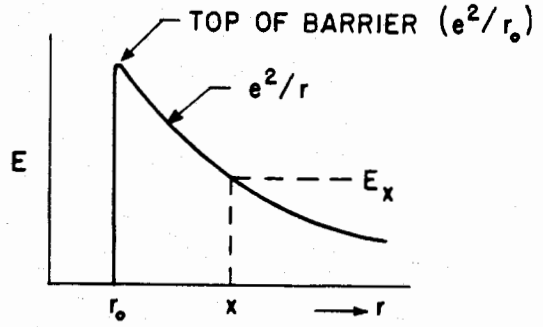


Fig. 8.1

charges and e is the unit (electronic) charge. Since Z and Z' are both unity for reactions between the isotopes of hydrogen, it is evident that these reactions involve lower potential barriers, and should occur more readily, than other nuclear reactions.

The potential barrier opposing the approach of two hydrogen nuclei is indicated in Fig. 8.1, in which the potential energy, E, equal to e^2/r, is plotted against the distance of approach of the nuclei. The potential energy is seen to drop sharply when the internuclear distance is r_o, for at this point the short-range attractive forces between the nuclei become effective. According to classical theory, therefore, the energy required to make nuclear reaction possible is equal to e^2/r_o, the potential energy at the top of the barrier.

As stated in Section 1.6, the energy e^2/r_o is of the order of 0.1 Mev; yet reactions between nuclei of hydrogen isotopes occur at appreciable rates at much lower energies. This fact has been explained by means of wave mechanics. According to classical theory, if the (kinetic) energy of a pair of nuclei is E_x (Fig. 8.1), they can approach no closer than a distance x. That is to say, they should be unable to come close enough to interact.

In terms of the wave mechanical concept, however, it can be shown that even though the energy is less than e^2/r_o, there is always a certain probability that the barrier will be penetrated and the nuclei will react. This probability is less the lower the nuclear energy, but it is, nevertheless, always finite, even though it may be very small. Consequently, nuclear reactions can occur at energies considerably less than that of the top of the potential barrier.

It may be noted that the probability of penetrating the potential barrier is greater for nuclei of low charge. This is another reason why reactions among isotopic hydrogen nuclei take place at lower energies than do those between nuclei of higher charge.

Of the reactions between pairs of nuclei of the three hydrogen isotopes, i.e., hydrogen ($_1H^1$), deuterium ($_1D^2$), and tritium ($_1T^3$), those involving H nuclei (or protons) are not important, mainly because the effective rates (or cross sections) of these reactions are relatively small.

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$$D^2 + D^2 \rightleftharpoons \begin{cases} He^3 + n^1 + 3.27 \text{ Mev} \\ T^3 + H^1 + 4.04 \text{ Mev} \end{cases}$$

$$D^2 + T^3 \longrightarrow He^4 + n^1 + 17.6 \text{ Mev}.$$

It is seen that there are two alternative D-D reactions; they take place roughly at the same rates, so that each may be regarded as occurring in half the D-D interactions.

D-D and D-T Cross Sections

The rate of a nuclear process is usually expressed in terms of the effective area per nucleus, i.e., the cross section. These cross sections can be determined experimentally by accelerating deuterons or tritons to known energies and determining the extent of interaction with other (stationary) nuclei. The results obtained for the second of the D-D reactions given above, represented by DD_p, and for the D-T reaction are shown in Fig. 8.2. The values for the other D-D reaction are very similar. The cross sections, $\sigma(E)$, are expressed in barns, i.e., in units of 10^{-24} cm^2, as a function of the deuteron energy in kev.

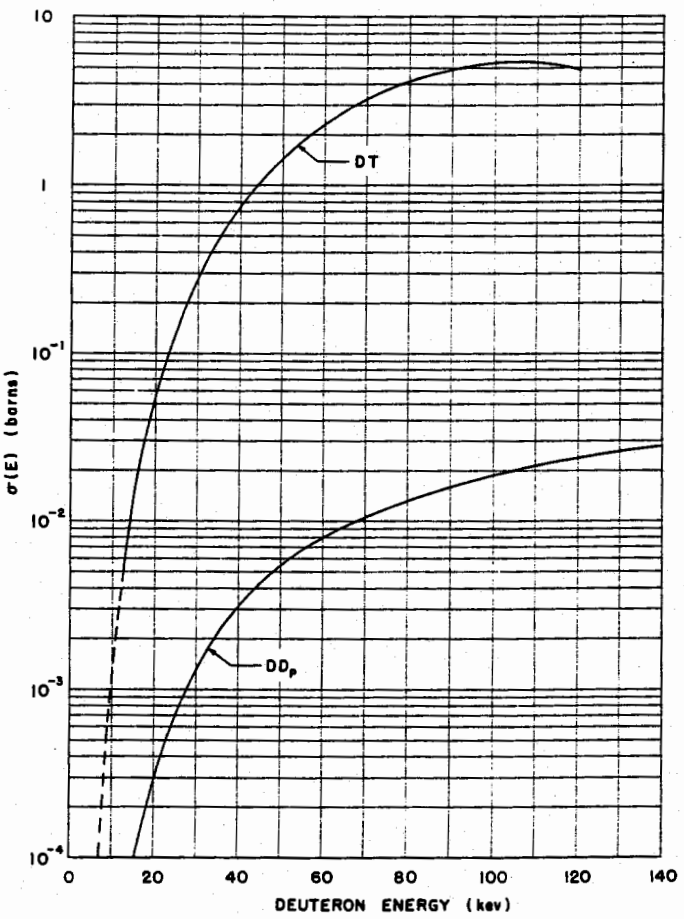


Fig. 8.2

The cross section, or reaction rate, is seen to increase with the energy, due to the increased probability of penetration of the potential barrier. It may be mentioned that the cross-section curve for the D-T reaction is not only somewhat higher than expected, but it also exhibits a maximum at energies around 100 kev (see Fig. 8.2). This is attributed to the phenomenon of resonance.

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Calculation of Reaction Rates

Consider a quantity of deuterium, and let the cross section, σ, represent the effective area of a nucleus of a given energy for the D-D reaction. If v is the velocity of the deuterium nucleus, then it will sweep out an effective volume σv in unit time, e.g., per sec. If there are N deuterons per cm^3, then the total effective volume swept out is σvN per cm^3 per sec. Since there are N deuterons present per cm^3, the number of effective D-D collisions, i.e., the rate of the D-D reaction, is equal to $\sigma vN^2/2$ per cm^3 per sec. The factor of one half is introduced here, for otherwise each D-D collision is counted twice. In the case of the D-T reaction, the corresponding rate would be σvN_dN_t per cm^3 per sec, where N_d and N_t are the numbers of deuterons and tritons, respectively, per unit volume.

It is seen from the foregoing argument that, apart from the density of the material, i.e., the number of nuclei per cm^3, the rate of a nuclear reaction is determined by the product σv. In a system at a given temperature, T, not all the nuclei will have the same energy and, hence, velocity.* The energies will, in fact, be distributed over a large range from very small to very large, as indicated qualitatively, in Fig. 8.3; $n(E)/n$ is the fraction of nuclei having energy E, per unit energy interval. If the energy distribution follows the Maxwell law, then the energy corresponding to the most probable velocity, per unit velocity interval, is equal to kT, where k is Boltzmann's constant; this is generally referred to as the energy corresponding to the temperature T.

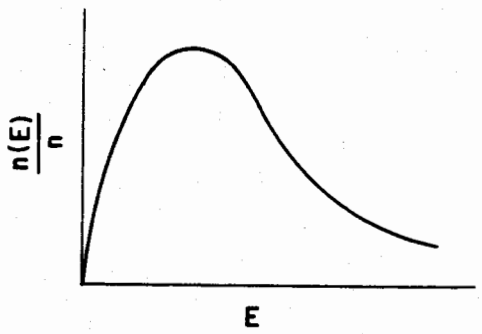


Fig. 8.3

As implied earlier, it has become the practice in the thermonuclear field to state the temperature as the energy kT, usually expressed in kev. Since k is 8.62×10^{-8} kev per degree, it follows that

$$\text{Temperature in kev} = 8.62 \times 10^{-8}\ T\ ,$$

where T is the absolute (Kelvin) temperature. Thus, a so-called temperature of 1 kev would correspond to a Kelvin temperature of 1.16×10^7 degrees.

*Since the energy E is kinetic, it is equal to $1/2\ mv^2$, where m is the mass of the nucleus; hence, v is determined by E, for a given species.

In order to determine the rate of a nuclear reaction at a given temperature, it is necessary to obtain a proper weighted average of σv, i.e., $\overline{\sigma v}$, over the whole energy range, since both σ and v vary with the nuclear energy. This can best be done by taking the experimental values of σ as a function of E (or of v), from Fig. 8.2, multiplying by the corresponding velocity, v, and then weighting each product according to the Maxwellian probability of that velocity. This operation may be expressed analytically by

$$\overline{\sigma v} = \frac{\int [\sigma(v)v] \; v^2 e^{-\frac{mv^2}{2kT}} \, dv}{\int v^2 e^{-\frac{mv^2}{2kT}} \, dv} , \qquad (8.5)$$

where the integrand in the denominator is the Maxwell factor. The values of $\overline{\sigma v}$ for one of the D-D reactions and for the D-T reaction, obtained somewhat in this manner, are plotted in Fig. 8.4 as a function of the temperature in kev. It is seen that, under equivalent density conditions, the D-T reaction is of the order of 50 to 100 times as fast as each of the D-D reactions at the same temperatures, at least in the range from 1 to 100 kev.

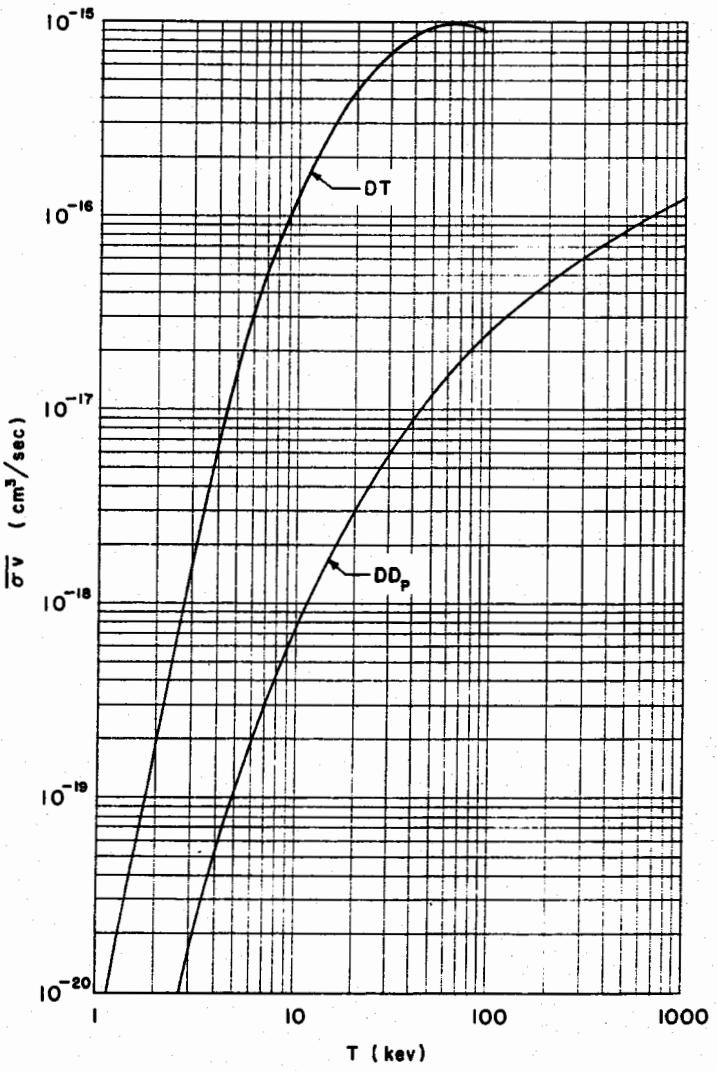


Fig. 8.4

The Reproduction Time

To illustrate the use of the data in Fig. 8.4, the energy reproduction time, i.e., the time required for the energy to double itself, in deuterium will be calculated. In every effective D-D collision, two deuterons are consumed, but in (roughly) half of these reactions a tritium nucleus is produced, which rapidly undergoes the D-T interaction with another deuterium nucleus. Thus, on the average, 2.5 deuterons are used up in every

effective collision.* From the arguments presented above, the number of effective D-D collisions is $\overline{\sigma v} N^2/2$ per cm^3 per sec, and so deuterons are consumed at the rate of $2.5\ \overline{\sigma v} N^2/2$ per cm^3 per sec. Since N is the number of deuterons present per cm^3, the fraction, F_t, of the deuterium reacting in time t sec is given by

$$F_t = \frac{2.5}{N}\ \overline{\sigma v}\ \frac{N^2}{2}\ t = 1.25\ \overline{\sigma v} N t\ , \qquad (8.6)$$

where t is assumed to be so short that N does not decrease appreciably.

If the two D-D reactions take place to, approximately, the same extent and every tritium nucleus formed rapidly undergoes the D-T reaction with another deuteron, the total energy liberated will be 4.04 + 3.27 + 17.6 = 24.9 Mev or, roughly, 25 Mev, for the consumption of five deuterons, i.e., 5 Mev or 5000 kev per deuteron. The energy ΔE produced in time t, per deuteron present in the system, is equal to F_t x 5000 kev, and so

$$\Delta E = 6250\ \overline{\sigma v} N t \text{ kev per deuteron.}$$

If E_{tot} is the total energy per deuteron present in the system, then the reproduction time, t_{rep}, i.e., the time required for the energy to double itself, due to the D-D and D-T reactions, is given by

$$t_{rep} = \frac{E_{tot}}{6250\ \overline{\sigma v} N}\ . \qquad (8.7)$$

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DOE 5(3)

Production of Lithium-6

The enrichment of lithium-6, from its normal isotopic proportion of 7.3 per cent to the 95 per cent or so desirable for thermonuclear devices, is carried out by a chemical, isotopic exchange process. Lithium amalgam, consisting of a solution of metallic lithium in mercury, is allowed to interact with an aqueous solution of lithium hydroxide in water. As a result of the exchange between the lithium isotopes in the mercury and those present as ions in the water, the ratio of lithium-6 to lithium-7, at equilibrium, is larger in the amalgam than in the aqueous solution. The separation coefficient is not much greater than unity, and appreciable enrichment is achieved by a continuous counter-current process. The lithium amalgam, flowing in one direction, becomes steadily richer in the Li^6 isotope, whereas the proportion of lithium-7 increases in the hydroxide solution. Because of the separation difficulties, highly enriched lithium-6 is still rare and costly.

8.6 Thermonuclear Tests

DOE 5(3)

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EXPERIMENTAL STUDIES OF TAYLOR INSTABILITY

Work done by:
John C. Allred
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Report written by:
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George H. Blount

PHYSICS

ACKNOWLEDGMENT

The work described in this report was undertaken at the behest, primarily, of Conrad Longmire and J. L. Tuck, to whom we are indebted for their continued interest and helpful discussions.

On account of the many specialized techniques which were required, we had need for consultation with various members of the Laboratory. A complete list would be long indeed, but we feel obliged to list the following as having been of great assistance in various phases of the work: Garrett Birkhoff, W. L. Briscoe, Berlyn Brixner, W. E. Buck, P. W. Byington, D. S. Carter, and R. E. Duff.

We wish also to note our appreciation of the very helpful cooperation of the Graphic Arts Group, under Loris Gardner and J. D. Elliott, and to Catherine Lacey and Opal Milligan of the Nuclear Microscopy Group for their assistance in analyzing the data.

Chapter 1

THE THEORY OF TAYLOR INSTABILITY

1.1 Potential Theory as Applied to Hydrodynamics

The equation of motion of a perfect fluid is[1]

$$\rho \frac{\partial v}{\partial t} + \rho v \cdot \nabla v = \rho F - \nabla p + 1/3\ \mu \nabla \nabla \cdot v + \mu \nabla \cdot \nabla v \tag{1.1}$$

where ρ is the density, v the velocity, F the body force (per unit mass), and μ the coefficient of viscosity. The equation of continuity is

$$\frac{d\rho}{dt} + \rho \nabla \cdot v = 0 \tag{1.2}$$

It can also be shown that the vorticity, ω, is given by

$$\omega = \frac{1}{2} \nabla x v \tag{1.3}$$

A very powerful method in hydrodynamics is that of potential theory, which enters when the motion is assumed to be irrotational and incompressible. For then

$$\frac{d\rho}{dt} = 0 \text{ and} \tag{1.4}$$

$$\nabla \cdot v = 0 \tag{1.5}$$

Further, since $\nabla x v = 0$, v is derivable from a scalar potential ϕ, owing to the vector identity $\nabla x \nabla \phi = 0$.

Hence

$$v = -\nabla \phi \tag{1.6}$$

where the negative sign is conventional and ϕ is called the velocity potential. ϕ satisfies Laplace's equation

$$\nabla^2 \phi = 0 \tag{1.7}$$

Under the conditions of incompressible, irrotational flow the equation of motion (1.1) becomes

$$\rho \frac{\partial v}{\partial t} + \rho v \cdot \nabla v = \rho F - \nabla p + \mu \nabla \cdot \nabla v \tag{1.8}$$

If we neglect viscosity and assume F to be derivable from a potential Ω (usually the gravitational potential), we can integrate the equation of motion to obtain Bernoulli's equation

$$\frac{p}{\rho} = \frac{\partial \phi}{\partial t} - \Omega - 1/2\ v^2 + f(t) \qquad (1.9)$$

We note that if the motion is steady, f(t) is a constant.

Hence the solution for the velocity potential in irrotational, incompressible flow is that solution of Laplace's equation which satisfies (1.9) together with the physical boundary conditions.

Sir Geoffrey Taylor[2] has used the potential theory to discuss the motion of the interface between two incompressible fluids in a gravitational field, neglecting surface tension and viscosity. His result is that an infinitesimal sinusoidal displacement of initial amplitude η_0 grows as

$$\eta = \eta_0 \cosh \alpha t$$

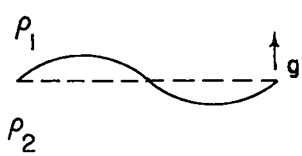
where $\alpha = \left[kg \frac{\rho_2 - \rho_1}{\rho_2 + \rho_1} \right]^{1/2}$, provided $\rho_2 > \rho_1$ and the gravitational field is directed from ρ_2 toward ρ_1.*

Taylor's solution neglects the term $\frac{\rho v^2}{2}$ in Bernoulli's equation in order to linearize the theory. This term has likewise been neglected by subsequent workers, although its effect is perhaps important in the development of asymmetries in the interface, as we shall presently suggest.

1.2 Derivation of Instability Criteria

Rigorous mathematical discussions of the Taylor instability are to be found in the literature and will not be repeated here. It is possible, however, to give approximate derivations which lead to the same results and possibly give more physical insight into the effects of various quantities than do the more elegant presentations.

To this end, let us consider the equation of motion of an interface in an acceleration field of magnitude g, as indicated in the sketch. If η is the displacement of the interface, the restoring force will be of the order of



$$f = -\eta \lambda g(\rho_2 - \rho_1)$$

and the mass which must be moved is, approximately, $(\rho_2 + \rho_1)\lambda^2$, since the circulation in a wave is of depth of order λ.

*We may here observe that the effect of a gravitational field is completely equivalent to the acceleration of a system in a direction opposite to that of the gravitational force. Hence we may say that the interface is unstable if the acceleration is directed from the lighter to the denser medium or, equivalently, when the gravitational field is directed from the denser to the lighter medium.

For the purpose of determining the physical existence of a density gradient at a water-isoamyl alcohol interface, we observed by the schlieren technique a cell containing water and isoamyl alcohol. This cell was one of the halves of the acceleration tube used in our Lewis apparatus. The schlieren photographs which resulted are shown as Figs. 4.8, 4.9, and 4.10; these show the progressive thickening in time of the region of optical density gradient. Similar observations on interfaces of water-n-heptane showed only a line at the interface, due to the curvature of the meniscus. An effect similar to that observed with water-isoamyl alcohol was seen to occur at a water-n-octyl alcohol interface. However, the effect was much less pronounced.

According to the theory of the Taylor instability one expects that initially the amplitude of a disturbance grows as cosh αt, where α is a reproduction factor and t is the time. Cosh αt is approximately represented by $e^{\alpha t}/2$, an approximation which becomes increasingly more valid as αt increases. In the later stages of the growth the theory predicts that the lighter fluid will penetrate the heavy fluid at constant velocity, in analogy with the constant rate of rise of bubbles, while the heavier fluid will be in free fall under an acceleration which is constant, but may be diluted by an Atwood factor.[12] Hence one would expect the amplitude to increase according to a form such as $a = a_o + vt + 1/2\ at^2$. In very late stages the term t^2 should predominate and one would expect that the amplitude would be simply proportional to t^2 To check these predictions, we have measured the amplitude of disturbances of various wavelengths as a function of the time. These measurements were made primarily from the 16-mm negatives by means of Leitz Ortholux microscopes at low magnifications. At the same time the estimated mean position of the interface was measured so that the acceleration could be determined. The results of a typical set of such measurements are shown in Figs. 4.11, 4.12, and 4.13. In Fig. 4.11 we have plotted the square root of the observed mean displacement of the interface against the time. The result is a straight line, the slope of which measures the acceleration. The intercept on the time axis indicates the time at which the acceleration began on the arbitrary time scale. Taking the time zero thus obtained as the true zero in time, we have plotted in Fig. 4.12 lnA vs true time. We observe that, while the scatter of the points is considerable, a straight line can be drawn reasonably well through the first portion of the curve. The slope of this line is a measure of the α which is observed experimentally.

In Fig. 4.13 $A^{1/2}$ vs t is plotted for a typical observation. It is seen that in the latter stages of the growth a linear relation applies between these two variables. The slope of the line in this region is a measure of the acceleration of the heavier fluid into the light. Table 4.2b gives a comparison of the observed values of α with those predicted by the linear theory of Taylor and that of Pennington, which has taken into account the effects of surface tension

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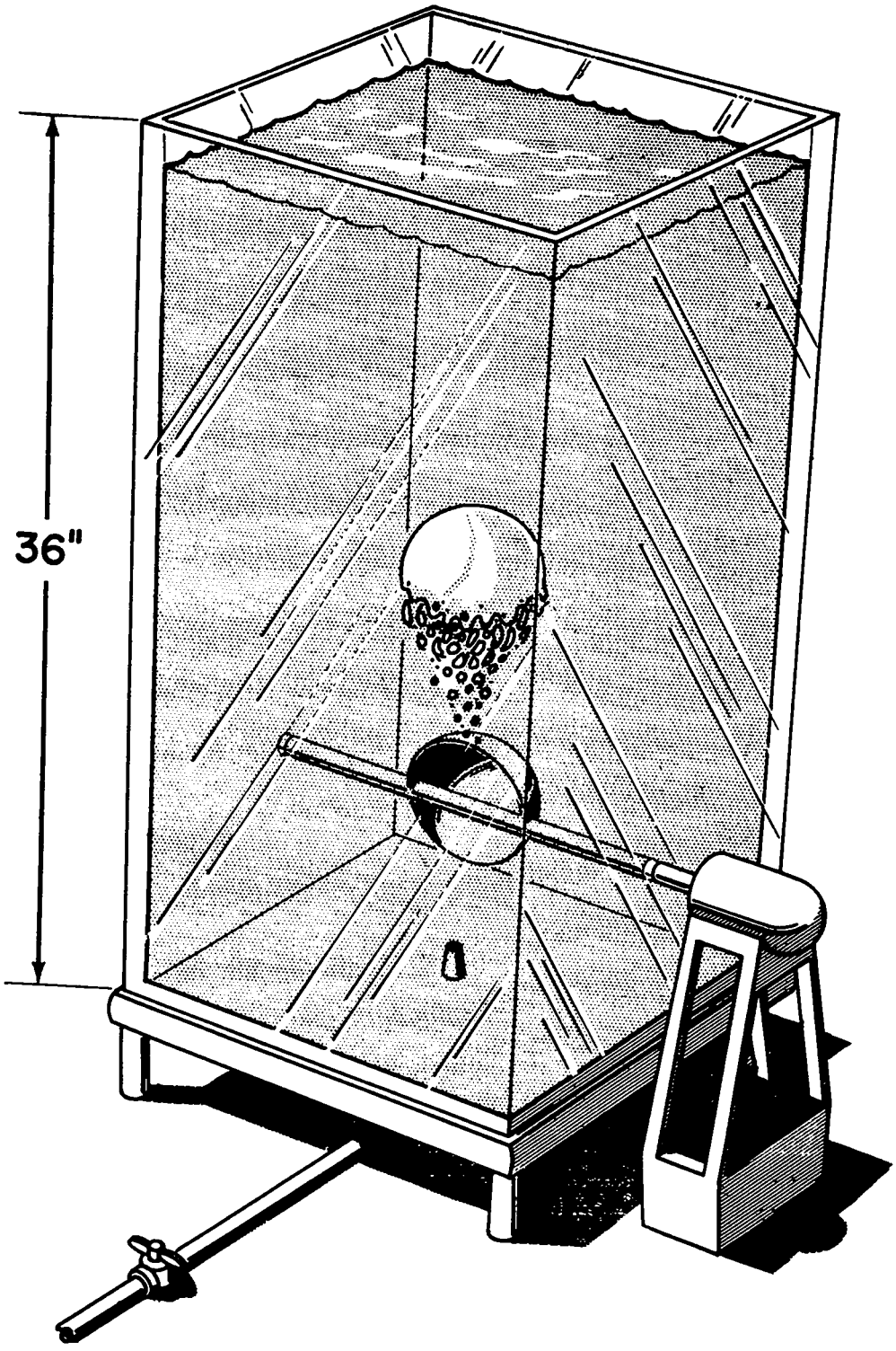


Fig. 3.1. Bubble tank.

Figs. 3.2 through 3.10

Development of Taylor instability on the upper surface of an air bubble in water. With an arbitrary time zero, the pictures are taken at the following times (milliseconds): t = 0, 16.7, 25.0, 33.3, 50.0, 58.3, 66.7, 83.3, 125.0. The horizontal grid in the background has a spacing of 2 inches.

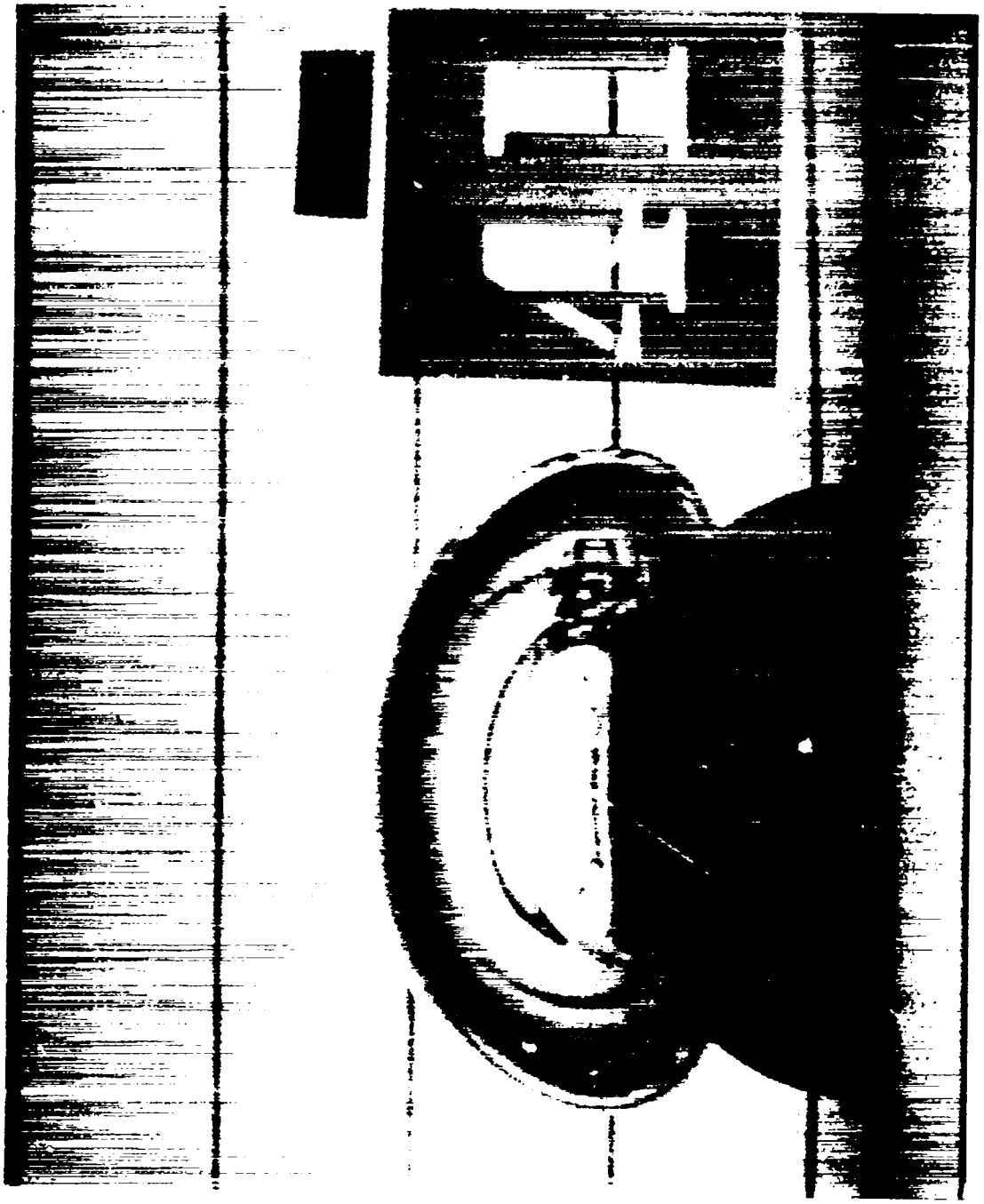


Fig. 3.2

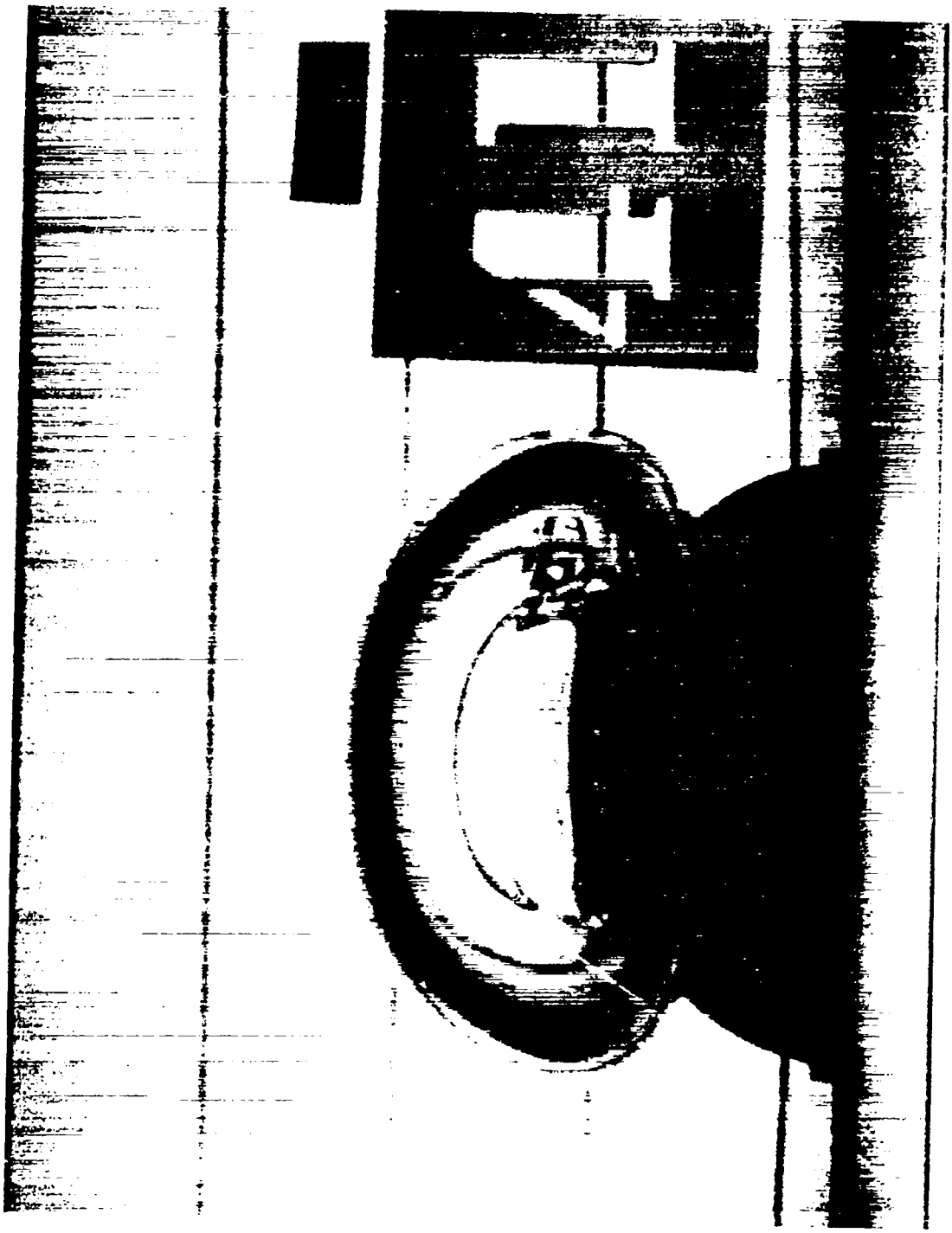


Fig. 3.3

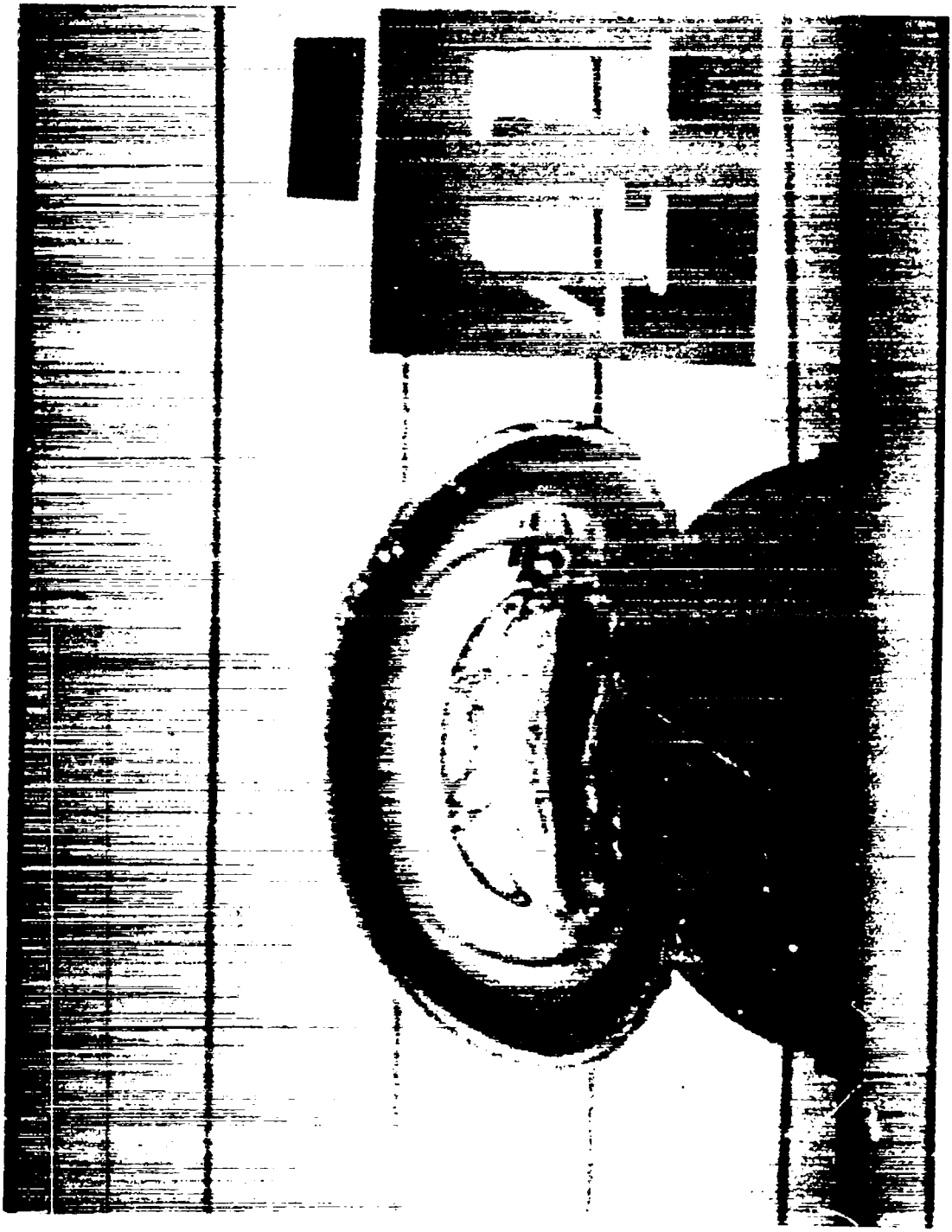


Fig. 3.4

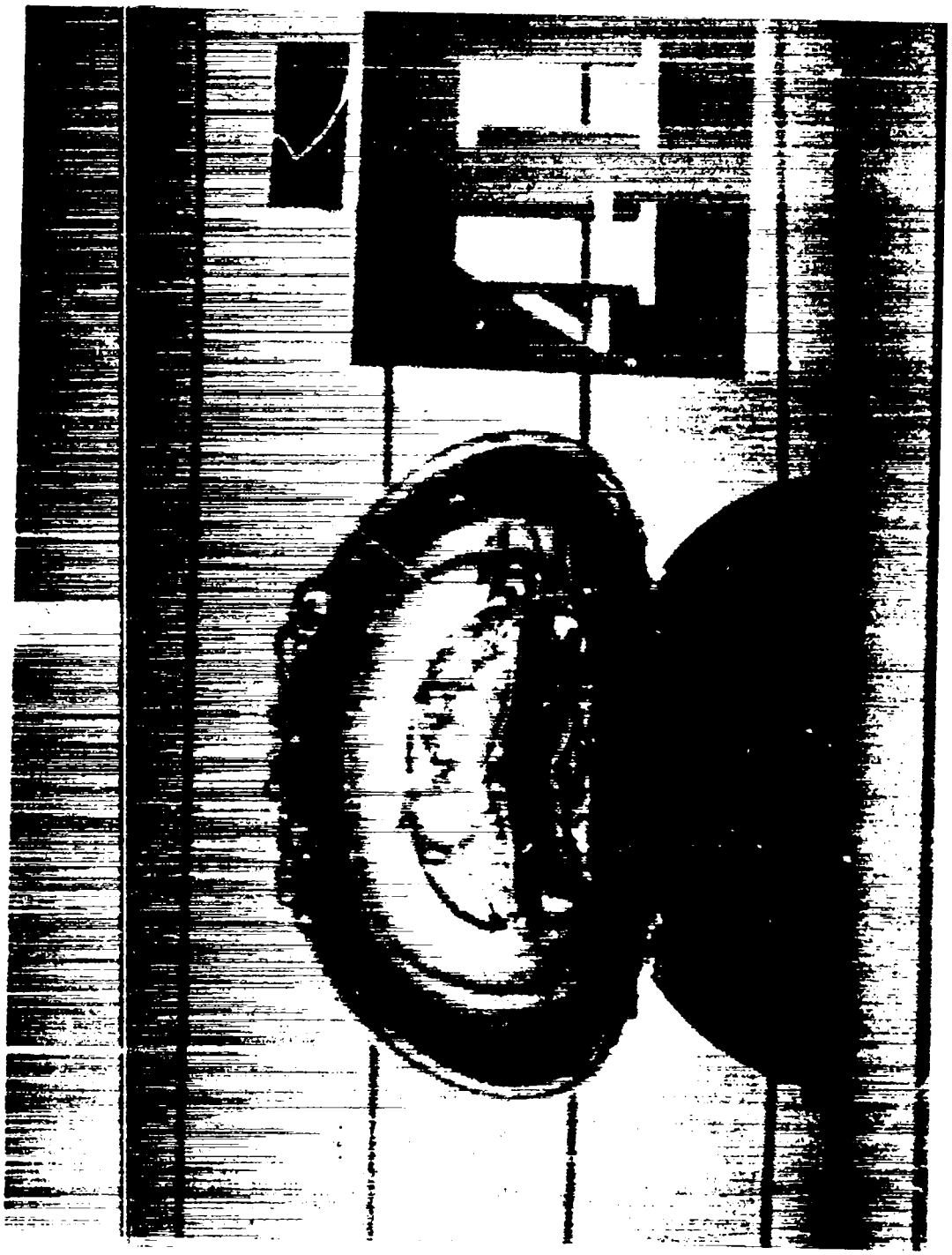


Fig. 3.5

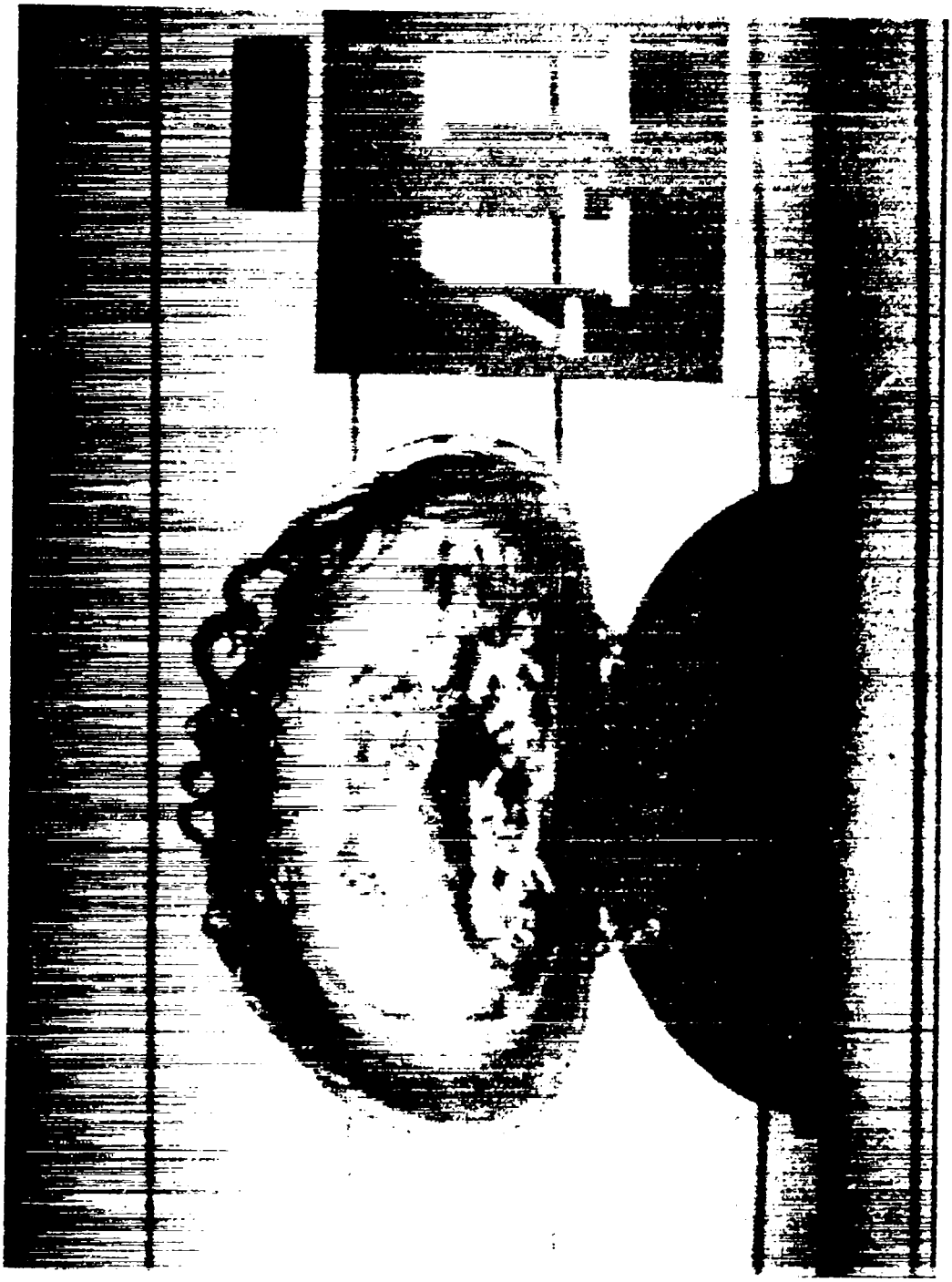


Fig. 3.6



Fig. 3.7

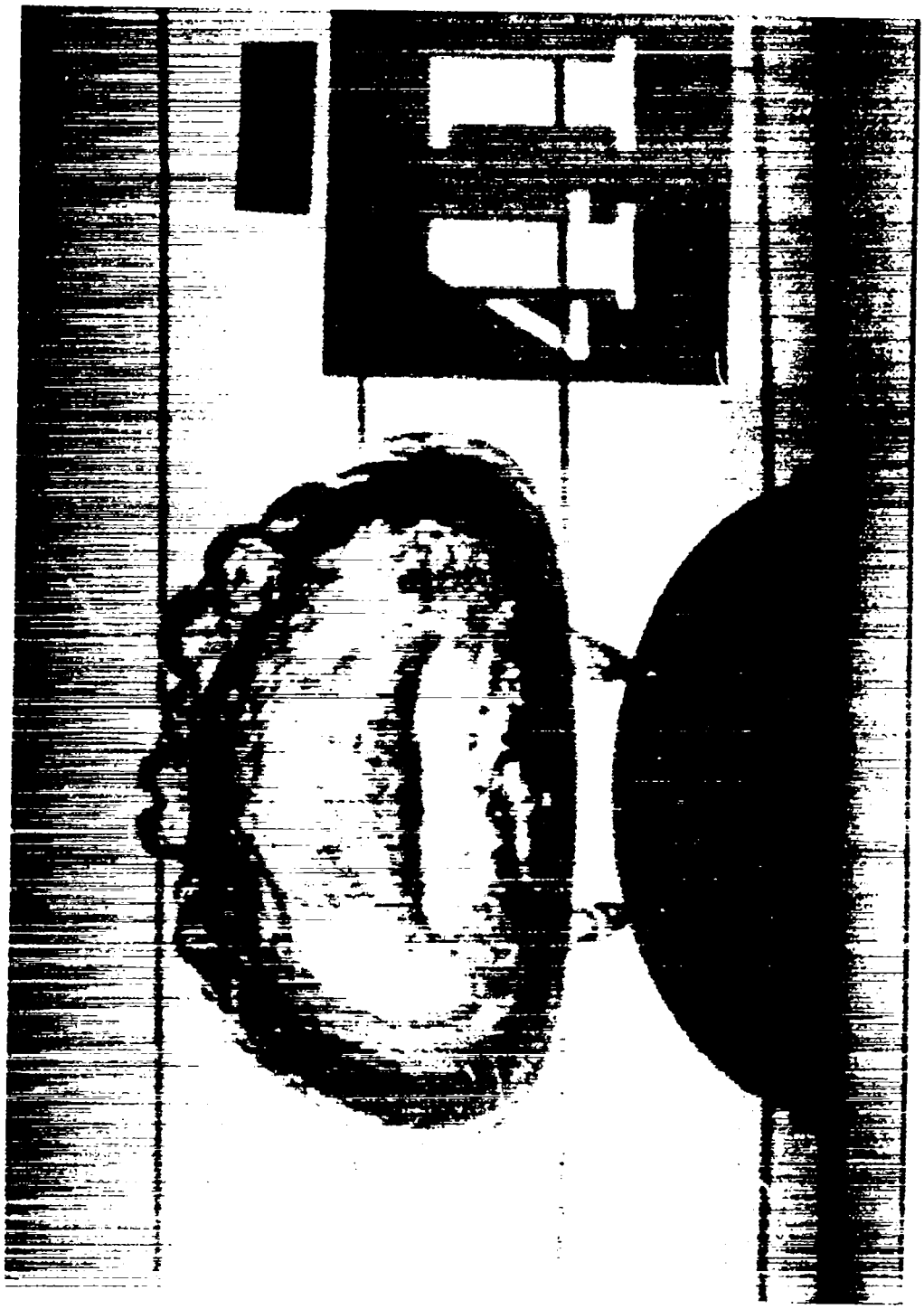


Fig. 3.8

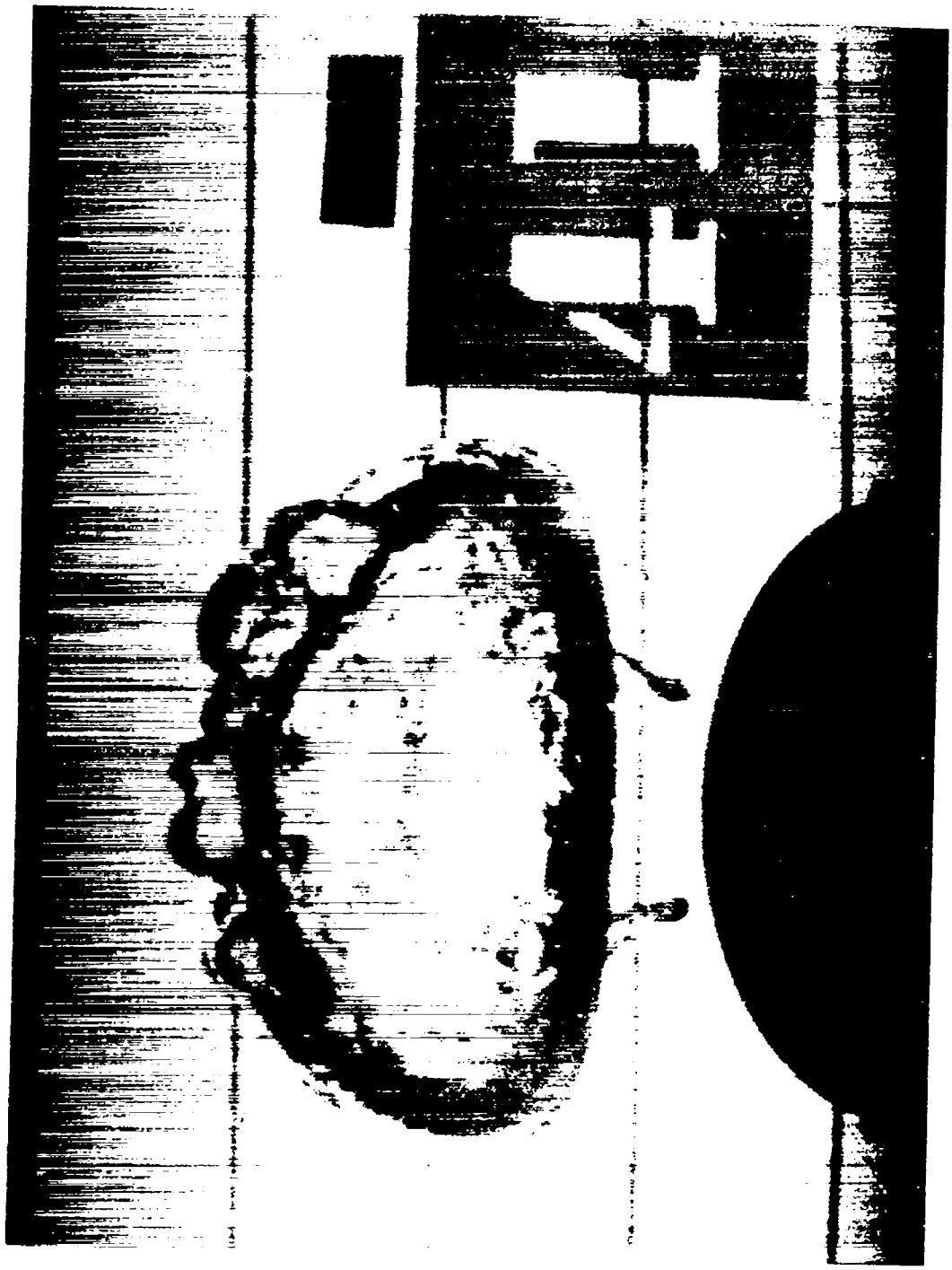


Fig. 3.9



Fig. 3.10

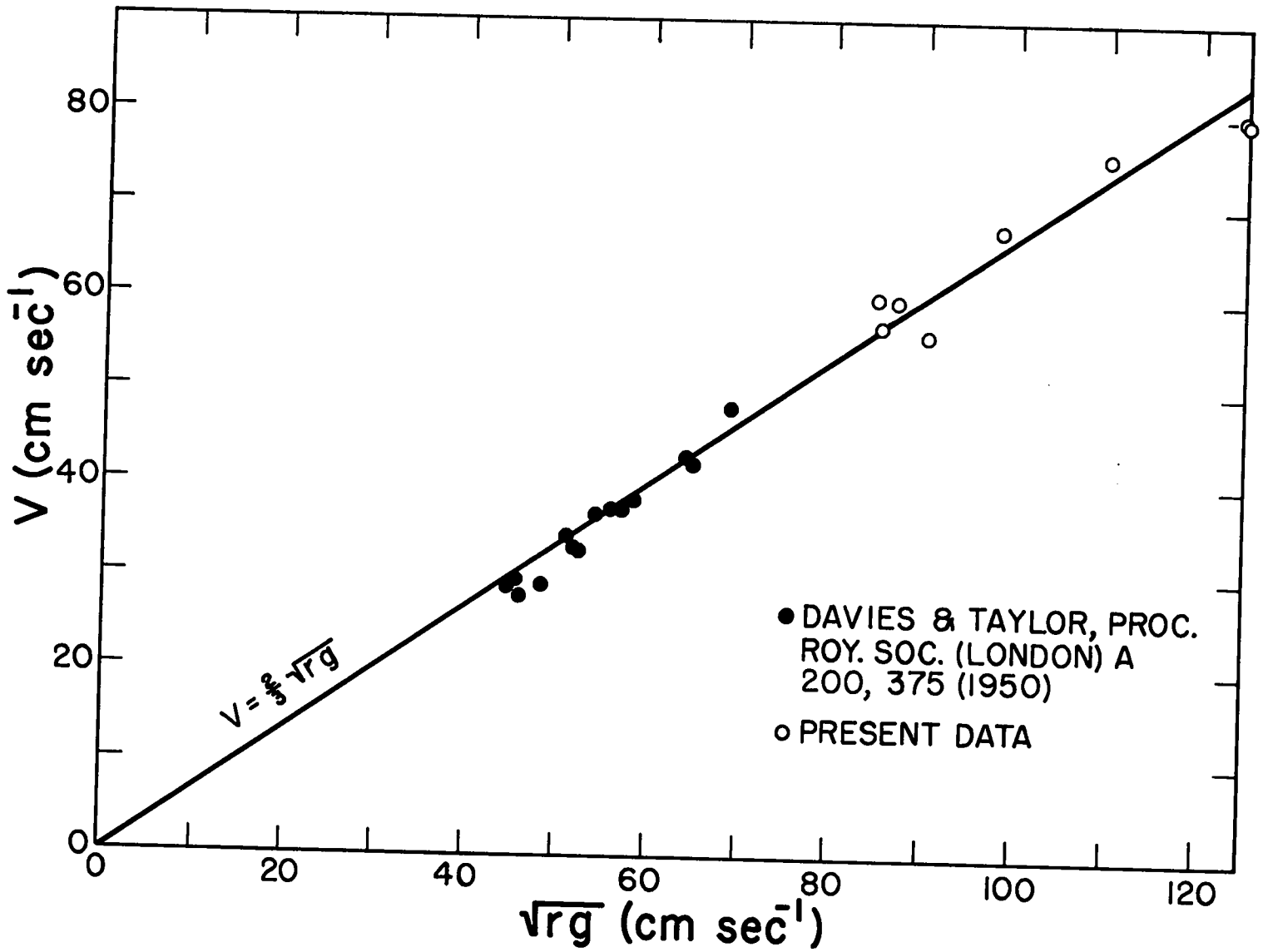


Fig. 3.11. Bubble velocity vs $(rg)^{1/2}$

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TAYLOR INSTABILITY IN SHOCK ACCELERATION OF COMPRESSIBLE FLUIDS

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ABSTRACT

The initial growth of irregularities on an interface between two compressible fluids is studied for impulsive (i.e., shock) acceleration. It was found that the ultimate rate of growth is roughly the same as that given by the incompressible theory, if the initial compression of the irregularities and of the fluids is taken into account.

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Chapter I -- INTRODUCTION

G. I. Taylor developed a theory of the growth of irregularities on the interface between two fluids of different densities when they are in accelerated motion. The fluids are assumed incompressible and the interface to have sinusoidal corrugations, so that the position of the interface in a suitably-oriented cartesian coordinate system is given by

$$z = a \cos kx \tag{1}$$

at some instant, where a and k are constants and where

$$k\,a \ll 1. \tag{2}$$

Then if there is an acceleration of the system as a whole and if g(t) represents the z-component of acceleration, the growth or decay of the amplitude a = a(t) of the corrugations satisfies the equation,

$$\frac{d^2}{dt^2}\,a(t) = k\,g(t)\,a(t)\,\frac{\rho_{(+)} - \rho_{(-)}}{\rho_{(+)} + \rho_{(-)}}, \tag{3}$$

where $\rho_{(+)}$ and $\rho_{(-)}$ are the densities of the fluids, on the +z and -z sides of the interface, respectively.

If viscosity, surface tension, compressibility are absent, (3) is rigorous so long as (2) continues to hold. If the irregularity consists of a superposition of sinusoidal corrugations, each satisfying (2), then

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each of them satisfies also (3) with its appropriate value of k. For constant acceleration directed toward the denser fluid, (3) gives an exponential growth of a(t). It is also known that after ka has reached about 1, from there on the increase of a is more leisurely, at about a constant rate (the shape is no longer sinusoidal). It is therefore generally assumed that (3) describes fairly well the growth of long-wave-length irregularities of small amplitude ($ka \ll 1$), even though irregularities of very short wavelength have gone out of the linear range near the beginning of the acceleration, since the fuzziness of the interface caused by the short-wave-length irregularities may extend only over distances small compared to the amplitudes of the longer-wave-length irregularities. (3) has been used for calculating the growth of irregularities for practical purposes.

In some practical cases, part or all of the acceleration is impulsive; i.e., g(t) is very large during a very short time interval and zero or small outside that interval. Let v be the increment of velocity imparted by this acceleration, $= \int g(t)\,dt$; then if the situation before the acceleration is

$$a = a_o, \qquad \frac{da}{dt} = 0, \qquad \text{(before)}, \tag{4}$$

the situation immediately after is:

$$a = a_o, \quad \frac{da}{dt} = k\,v\,a_o\,\frac{\rho_{(+)} - \rho_{(-)}}{\rho_{(+)} + \rho_{(-)}} \quad \text{(immediately after)} \tag{5}$$

as can be seen by integrating (3).

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The limiting case of impulsive acceleration is acceleration by a shock. In this case the compressibility of the fluids certainly cannot be neglected, so that (3) cannot be used. The object of study reported here is to compute the growth of irregularities when a shock sweeps across a corrugated interface from a less dense to a more dense fluid.

In Fig. 1 are schematic before-and-after pictures, showing the incident shock, which is assumed plane, and the transmitted and reflected shocks, which are corrugated. Before the arrival of the shock, the materials are at rest, in accordance with the initial conditions (4). Pressure is assumed constant behind the incident shock.

It is clear that immediately after the passage of the shock, as depicted schematically in Fig. 1, the conditions will not be as given by (5), above. Instead, the amplitude a will be somewhat less than a_o, because of the overall compression of the fluids, and furthermore $\frac{da}{dt}$ will be zero, because the forward velocity imparted by the shock to the crest of the corrugation will be the same as that imparted to the trough, and $\frac{da}{dt}$ is simply one-half the difference of these. Until there has been time for communication, by sound signals, of effects over distances comparable with 1/k, there can be no difference in behavior between crest and trough. (In the incompressible theory, effects are transmitted instantaneously by fluid pressure, so that $\frac{da}{dt}$ can acquire a non-vanishing value immediately, as stated in (5) above.)

But as time goes on, the amplitude of the corrugation of the

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interface begins to grow, because near the crests, where the heavy fluid protrudes farthest into the light, the transmitted shock is slightly converging and the reflected shock slightly diverging; this produces a slight pressure excess in the heavy fluid and deficiency in the lighter, whereas at the troughs of the corrugations, the reverse situation holds; and these pressure perturbations are in such directions as to hold back the crests but accelerate the troughs into the heavy fluid. Our aim is to calculate these pressure perturbations and from them the motion of the interface.

One may surmise that by the time the shocks have moved to distances several times $1/k$ from the interface, the net result will be qualitatively as for the incompressible case; namely, the amplitude will have acquired a rate of change $\frac{da}{dt}$ of the same order of magnitude as that given by (5), and thereafter $a(t)$ will increase practically linearly with time. If the limiting value of $\frac{da}{dt}$ should be much greater or much less than for the incompressible case, this would perhaps be of practical importance in some problems, and would indicate the extent to which equation (3) is invalidated by effects of compressibility.

Chapter II - BASIC EQUATIONS.

Sec. 1. General. Referring to Fig. 1, we take a comoving coordinate system, after the primary shock has crossed the interface, in which the mean position of the interface is $z = 0$. Let w_1 and w_2

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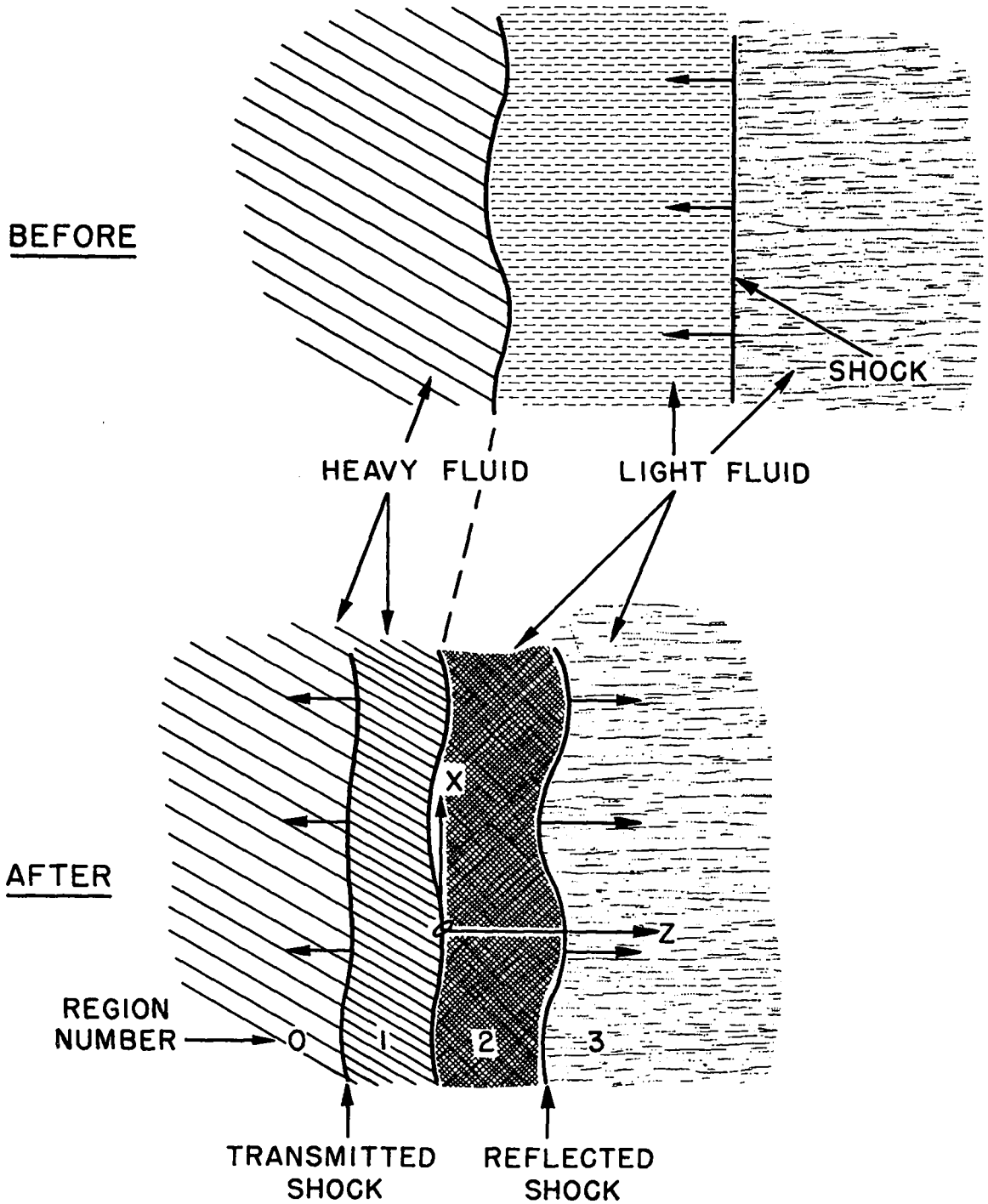


Fig. 1

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September 1955

Report distributed: May 2, 1956

LA-1927

TAYLOR INSTABILITY
APPENDICES TO REPORT LA-1862

by

Garrett Birkhoff

PHYSICS

(Distributed according to
TID-4500, 11th edition)

INTRODUCTION

The material below consists of a more elaborate analysis of various topics discussed in Report LA-1862, "Taylor Instability and Laminar Mixing". These topics are covered in a series of eight appendices, as follows:

		Page
Appendix A	Remarks on Similarity	5
Appendix B	Initial Acceleration	9
Appendix C	Stability of Heterogeneous Fluids	22
Appendix D	Steady State Bubble Rise	23
Appendix E	Remarks on Layzer's Model	49
Appendix F	Calculation of Interface Motion	52
	Note by E. Fermi: Taylor Instability of an Incompressible Fluid	67
Appendix G	Motion of Polygonal Interface (Fermi Model)	75
Appendix H	Globule Acceleration	85

TAYLOR INSTABILITY OF AN INCOMPRESSIBLE LIQUID

by

Enrico Fermi
September 4, 1951

This is an attempt to discuss in a very simplified form the problem of the growth of an initial ripple on the surface of an incompressible liquid in presence of an acceleration, g, directed from the outside into the liquid.

The model is that of a heavy liquid occupying at $t = 0$ the half space above the plane $z = 0$. It is well known that this is a state of unstable equilibrium. Any tiny ripple on the surface at the initial time grows in amplitude, first exponentially and later, when its amplitude has become comparable to the wavelength, by a more complicated law.

The case will be considered that there is initially a small amplitude sinusoidal ripple of wavelength λ. In a first phase this amplitude will increase exponentially like

$$\exp\left(\sqrt{\frac{2\pi g}{\lambda}}\, t\right) \tag{1}$$

This exponential law, however, will break down when the amplitude has become comparable to $\lambda\!\!\!^{-} = \lambda/2\pi$. We propose to discuss what happens in the subsequent phase.

This will be done by grossly schematizing the shape of the wave as indicated in Fig. 1.

Instead of a wave profile like the curve, a profile like ABCDEFGHIJ will be assumed.

It is clear from the symmetry of the problem that the points at the maximum and the minimum of the wave move in vertical directions. In Fig. 2 a half wave, from a maximum to the successive minimum is represented with the notations adopted. OO' is the initial level of the liquid. On account of the incompressibility, the amount of liquid below the plane OO', namely CO'DE must be equal to the amount of liquid ABCO missing from above. This condition leads immediately to the relationship

$$b = \frac{ax}{1-x} \tag{2}$$

Our schematic wave profile is then characterized by the two parameters a, x. The problem is to determine how they vary with time.

In principle the problem so simplified could be solved by expressing the kinetic energy T and the potential energy U of the liquid contained between the two boundaries OA, O'E as functions of a, x, $\dot{a}$, $\dot{x}$.

$$T = T(a, x, \dot{a}, \dot{x})$$

$$U = U(a, x)$$

One can then write the Lagrange equations

$$\frac{d}{dt}\frac{\partial T}{\partial \dot{x}} - \frac{\partial T}{\partial x} = -\frac{\partial U}{\partial x}; \quad \frac{d}{dt}\frac{\partial T}{\partial \dot{a}} - \frac{\partial T}{\partial a} = -\frac{\partial U}{\partial a} \tag{3}$$

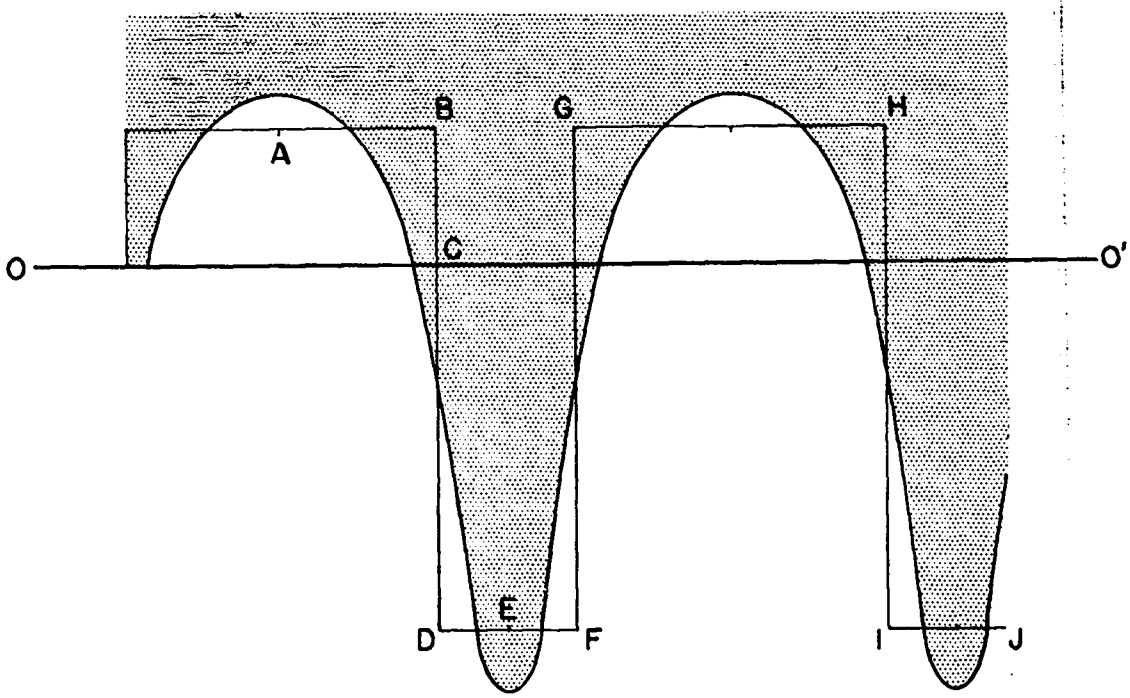


Fig. 1

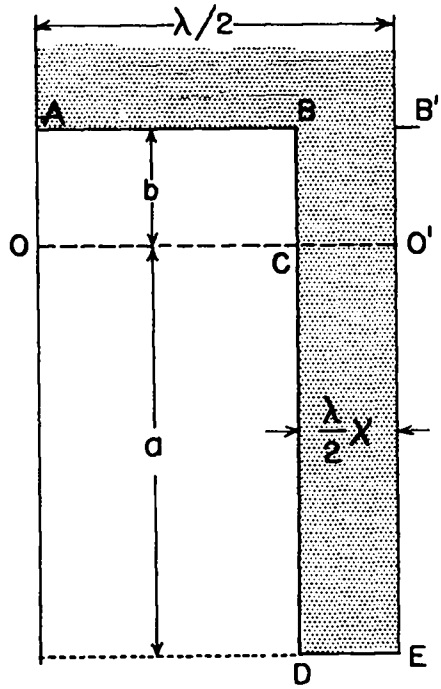


Fig. 2

which describe the law of variation of the two wave parameters $\underline{a}$, $\underline{x}$.

The potential energy U can be written down immediately. It is due to having moved the liquid originally contained in ABOC (weight per unit length perpendicular to the plane of the drawing = $\rho g \frac{\lambda}{2} b(1 - x)$, height of the center of gravity = $b/2$) to the lower position CDEO' with the center of gravity at a height $-a/2$.

In what follows the following unit will be used: unit of length, $\frac{\lambda}{2}$; unit of acceleration, g; unit of density, ρ.

One finds, then, the potential energy

$$U = -\frac{1}{2}\frac{a^2 x}{1-x} \tag{4}$$

The calculation of the kinetic energy is more difficult. In principle it could be carried out for a prescribed motion of the profile of the liquid by solving a Dirichlet problem. Instead of doing this, a much cruder method was followed in keeping with the crude approximation chosen for the profile of the wave.

When the amplitude of the wave is very large, it is evident that the kinetic energy is due primarily to the vertical component of the liquid velocity inside the domain BDEB'. The corresponding kinetic energy can be computed easily on the assumption that the vertical component of the velocity is constant on each horizontal section of BDEB'. One finds that this part of the kinetic energy is given by

$$T_1 = \frac{a^3 x^2}{6x(1-x)} \tag{5}$$

For small and moderate amplitudes of the wave, additional terms in the kinetic energy become important. One of them is the kinetic energy due to the horizontal component of the motion of the liquid BDEB'. This term of the kinetic energy is given approximately by

$$T_2 = \frac{a x \dot{x}^2}{6(1-x)} \tag{6}$$

Finally, the kinetic energy due to the motion of the liquid above the line AB' should be estimated. An approximate expression for this term of the kinetic energy yields

$$T_3 = \frac{\pi}{4} \frac{a^2 \dot{x}^2}{(1-x)^2} + \frac{\pi}{2} \frac{a x \dot{a} \dot{x}}{1-x} + \frac{\pi}{4} x^2 \dot{a}^2 \tag{7}$$

The kinetic energy is the sum of the three terms (5), (6), (7)

$$T = T_1 + T_2 + T_3 \tag{8}$$

As pointed out, the leading term at high amplitude is the first. For low amplitude all the three terms need to be considered.

Using the expressions (4) and (8) for potential and kinetic energy, one can write the Lagrange equations (3). That enables one to express the second time derivatives x and a in terms of x, a, $\dot{x}$, $\dot{a}$. One finds

$$\ddot{x} = \frac{ED-FB}{AB-BC}, \quad \ddot{a} = \frac{AF-EC}{AD-BC} \tag{9}$$

where

$$A = \frac{a^2}{3y} + \frac{y}{3} + \frac{\pi}{2} a, \quad D = a + \frac{\pi}{2} y$$

$$B = \frac{a}{2} + \frac{\pi}{2} y, \qquad C = \frac{a^2}{2y} + \frac{\pi}{2} a \tag{10}$$

$$E = \frac{a}{2} - \frac{\dot{a}^2}{2} - \frac{1}{6}\,\frac{(4x-1)a^2\dot{x}^2}{y^2} - \frac{a\dot{a}\dot{x}}{y} - \frac{\dot{x}^2}{6} - \frac{y\dot{x}\dot{a}}{3a} - \frac{\pi}{2}\,\frac{xy\dot{a}^2}{a} - \frac{\pi}{2}\,\frac{ax\dot{x}^2}{y} - \pi\dot{x}\dot{a}$$

$$F = a - \frac{\dot{a}^2}{2} + \frac{(1-2x)a^2\dot{x}^2}{2y^2} - \frac{a\dot{x}\dot{a}}{y} + \frac{\dot{x}^2}{6} - \pi\frac{y\dot{x}\dot{a}}{x} \qquad (11)$$

and

$$y = x(1-x) \qquad (12)$$

These equations have been integrated numerically by Miriam Caldwell. Initial conditions corresponding to a wave of very low amplitude were chosen as follows: $a = .01$, $\dot{a} = .0177$, $x = .5$, $\dot{x} = 0$. The results of the numerical integration are given in Table I.

t	a	b	x
0	.0100	.0100	.500
.5	.0243	.0228	.484
1.0	.0628	.0468	.427
1.5	.192	.083	.303
2.0	.584	.115	.165
2.5	1.218	.144	.106
3.0	2.195	.170	.072

Table I

The four columns of the table give, respectively: the time in units $\sqrt{\frac{\lambda}{2g}}$; the two amplitudes of the wave, a and b, below and above the original surface of the liquid expressed in units $\lambda/2$; and the quantity x that measures the asymmetry of the wave ($x = .5$ corresponding to a symmetrical wave). $x < .5$ corresponds to a wave in which the half wave below the original liquid surface is narrower than the half wave above. From an inspection of the table one will recognize that up to about

$t = 1$, the two amplitudes, $\underline{a}$ and $\underline{b}$, have rather close values and they grow approximately exponentially with a period not far from the one computed from the correct hydrodynamical theory of small amplitude waves

$$T = \sqrt{\frac{\lambda}{2\pi g}} = \frac{1}{\sqrt{\pi}} = .56 \quad \text{(in our units)} \tag{13}$$

Already, at $t = 1$, an appreciable asymmetry of the wave has developed. This becomes more and more noticeable for later times. At $t = 3$, for example, b is less than 1/10th of a.

The asymptotic behavior of $\underline{a}$, $\underline{b}$, and $\underline{x}$ for large values of the time is obtained from a discussion of equations (9). One finds that $\underline{a}$ increases proportionally to the square of the time, b increases proportionally to the square root of the time, and x is inversely proportional to the $3/2$ power of the time. More precisely, one finds the following limiting expressions

$$a \longrightarrow \frac{4}{7}(t - 1.04)^2 \tag{14}$$

$$b \longrightarrow .12\,(t - 1.04)^{1/2} \tag{15}$$

$$x \longrightarrow .21\,(t - 1.04)^{-3/2} \tag{16}$$

In other words, the lower tip of the wave falls with uniformly accelerated motion and with acceleration equal to $8g/7$. The upper half wave grows much slowly and its velocity decreases with time.

It is interesting to compare the results of this crude approximation with the experimental results obtained by D. J. Lewis,[1] as well as

---

[1] PRS 202A 81, 1950

with the results of G. I. Taylor[2] and of Taylor and Davies.[3] The present theory seems to represent correctly one feature of experimental results, namely the fact that the half wave of the heavy liquid into the vacuum becomes rapidly narrower, whereas the half wave pushing into the heavy liquid becomes more and more blunt. On the other hand, the present theory fails to account for the experimental results according to which the front of the wave pushing into the heavy liquid moves with constant velocity. According to the present theory the displacement is expected instead to be proportional to the square root of the time.

---

[2] PRS 201A 192, 1950

[3] PRS 200A 375, 1950

[redacted]

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THE TURQUOISE BOOK

OPERATION IVY

[redacted] Shurtleman 9/26/79

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Per DORIS H. DURNING
(Person authorizing change in classification and date)

By Evelyn Stephenson 6/2/79
(Signature of person making the change and date)

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J Diaz 3/25/86
DATE

Headquarters
Task Group 132.1
Los Alamos Scientific Laboratory
15 May 1952

[redacted]

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[redacted]

Major General P. W. Clarkson
Commander, Joint Task Force 132
Washington, D. C.

Dear General Clarkson:

One of the missions assigned the Commander Task Group 132.1 for Operation IVY is that of conducting technical measurements programs for the Atomic Energy Commission and the Department of Defense. The Turquoise Book attempts to "tell the story" behind these programs - the why as well as the where, when and how. Our Scientific Deputy, Dr. William E. Ogle, and his staff, have reviewed the material contained herein, in order that its readers may be assured that the why is correct and that the how is up to date as we go to press. In addition, Dr. Alvin C. Graves has indicated his agreement with the underlying philosophy of the individual presentations.

The basic purpose of such a publication is to present, in a form acceptable to prospective readers representing varied professions, the object of each experiment and the general manner in which it is to be conducted. It is true that we have included miscellaneous allied information as to project ownership and approximate personnel involved; however, as a word of caution, the Turquoise Book cannot be considered as a document for accurate personnel and fiscal accountability, nor does it present a definitive account of Atomic Energy Commission and Military support. There are established sources for these types of supporting information.

In the intervening period, prior to boarding the USS ESTES during the early morning hours of MIKE Day, changes in the detailed methods of conducting individual projects will undoubtedly be made. As you well appreciate, this is the way of scientific experimentation. All we can say now is that this is how we see the fifty-eight experimental projects on Thursday, 15 May 1952, M-169. Subsequent changes will be reflected in the official reports and history of the operation.

S. W. BURRISS
Commander, T.G. 132.1

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IVY EXPERIMENTAL PROGRAM BY PROJECT TITLE AND SPONSORING AGENCY

PROJECT NUMBER	TITLE
	PROGRAM 1 - RADIOCHEMISTRY
1.1	Yield Measurements.
1.2	Internal Nuclear Detector Measurements.
1.3	Sample Collecting.
	PROGRAM 2 - PROGRESS OF THE NUCLEAR REACTION
2.1a	Alpha of the Fission Phase.
2.1b	KING Alpha
2.2	Timing in the Fission Phase.
2.3	Rise of the Fusion Reaction.
2.4	Propagation of the Fusion Reaction.
2.5	Measurement of Transit Time.
	PROGRAM 3 - SCIENTIFIC PHOTOGRAPHY
3.1	Ball-of-fire Yield.
3.2	Cloud Phenomena.
3.3	Hot-spot Observation.
3.4	Bomb Case Motion.
3.5	Illumination as a Function of Time, with GR-Slit Cameras.
3.6	Ehangmeters.
3.7	Preliminary Photographic Crater Survey.

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PROJECT NUMBER	TITLE
3.8	Burst Position.
	PROGRAM 4 - NEUTRON MEASUREMENTS
4.1	Slow Neutron Observations.
4.2	High Energy Neutron Observations.
4.3	Neutron Spectrum - Nuclear Emulsions.
4.4	Neutron Intensity as a Function of Time.
	PROGRAM 5 - GAMMA-RAY MEASUREMENTS
5.1	Total Dose.
5.2	Gamma Intensity as a Function of Time.
5.3	Fall-out Gamma Intensity.
5.4a	Fall-out Intensity and Particle Size.
5.4b	Close-in Particulate Cloud and Fall-out Study.
	PROGRAM 6 - BLAST MEASUREMENTS
6.1	Pressure vs Time on the Ground.
6.2	Air Mass - Motion Studies.
6.3	Shock Wind and Afterwind.
6.4a	Water Wave Motion - Shallow Water - Photographic.
6.4b	Sea Waves.
6.5	Ground Motion - Seismic Measurements.
6.7a	Underwater Pressures as a Function of Time and Peak Water Pressure as a Function of Distance.

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PROJECT NUMBER	TITLE
6.7b	Underwater Pressures - Along Reef.
6.7c	Acoustic Pressure Waves in Water.
6.9	Air Density.
6.10	Free Air Pressure as a Function of Time (Manned Aircraft).
6.11	Free Air Pressure as a Function of Time Utilizing Parachute Suspended Canisters.
	PROGRAM 7 - LONG RANGE DETECTION
7.1	Electromagnetic Effects from Nuclear Explosion.
7.2	Airborne Low-frequency Sound from Atomic Explosion.
7.3	Calibration Analysis of Close-in A-Bomb Debris.
7.4	Propagation of Seismic Waves.
7.5	Transportation of Airborne Debris.
7.6	Detection of Fireball Lights at Distances.
	PROGRAM 8 - THERMAL RADIATION MEASUREMENTS
8.1	Integral Thermal Radiation.
8.2	Thermal Intensity as a Function of Time.
8.3	Spectroscopy.
8.4	Air Attenuation.
8.5	Thermal Radiation as a Function of Time in Free Air Utilizing Manned Aircraft.

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PROJECT NUMBER	TITLE
	PROGRAM 9 - ELECTROMAGNETIC PHENOMENA
9.1	Electromagnetic Signals.
9.2	Effects on the Ionosphere with Respect to the Propagation of Radio Waves.
9.3	Measurement of the Effects of an Atomic Explosion on Radio Propagation.
9.4	Evaluation of Indirect Bomb Damage Assessment Techniques.
	PROGRAM 10 - TIMING AND FIRING
10.1	Timing and Firing.
10.2	Release tone.
	PROGRAM 11 - PRELIMINARY GEOPHYSICAL SURVEY OF THE TEST AREA
11.1	Soundings of the Ocean Side of Eniwetok Reef.
11.2	Scaled Ground Shock Tests.
11.3	Deep Drilling to Base Rocks.
11.4	Seismic Surveys.

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PROGRAM 2

PROGRESS OF THE NUCLEAR REACTION

Project No: 2.1a

Project Title: Alpha of the Fission Phase.

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Dr. Ernst H. Krause
Address: Radiation Division
Naval Research Laboratory
Washington 25, D. C.

Phone: Johnson 3-6600
EXT. 864

Conducting Agency: Radiation Division
Naval Research Laboratory

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* See "Remarks" on page 2.1a.4.

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Object of the Experiment:

Regardless of whether the desired thermonuclear reaction takes place, it is important that we have information as to how the fission phase operated. To obtain such information, it is natural to fall back on the classical diagnostic measurements for fission weapons, such as the measurement of alpha and yield. Fission yield measurements will, of course, be without significance in the presence of a large scale thermonuclear reaction. Hence one must rely upon the measurement of alpha as a primary indication of the proper functioning of the fission aspect of the reaction.

Method and Procedure:

A. The number of neutrons present at a given time in any array of fissionable material can be shown to be approximated by:

$$N = N_o e^{\alpha (t - t_o)}$$

in which N_o represents the number of neutrons present at time t_o. The number is a measure of the neutron multiplication rate in the array - and a positive alpha is indicative of a supercritical array. The alpha of an implosion weapon is not truly constant, but varies with the degree of criticality produced by the implosion and subsequent explosion. In fact, there is no true alpha immediately after initiation - the magnitude of the neutron population being governed by the statistical behavior of individual neutrons. Very soon, however, the total number of neutrons present becomes sufficiently large that the statistical behavior of individual particles represents a small percentage of the overall effect. Then equation (1) becomes valid, and alpha increases until the assembly is most critical - remains relatively constant throughout the so-called "incubation" period - and decreases to negative values as the weapon disassembles and becomes sub-critical. Documentation of alpha versus time, and particularly the value of alpha during the incubation period, is an extremely valuable tool for use in post-shot deduction of how a fission weapon behaved.

The classical method of measuring alpha is an indirect one, involving the measurement of gamma-ray fluxes. This is feasible since the number of gamma rays given off is proportional to the neutron population, which is in turn proportional to the number of fissions - and nuclear theory supplies us with these proportionality factors.

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The gamma-ray flux during this period of interest is determined by placing a phosphor-photocell detector near the case of the device. The phosphor is a quantity of material that fluoresces with high efficiency under gamma ray bombardment. The fluorescing process, of course, creates a light source which is observed by the photocell. The light output of the phosphor, and hence the signal produced by the photocell used to measure this light, is proportional to the instantaneous value of the gamma-ray flux. This signal is piped through coaxial cables to a relatively distant oscilloscope and applied to the horizontal plates. A constant high frequency sinusoidal signal is applied to the vertical plates of the scope to supply a time record, and the combination of these signals supplies a scope trace from which alpha can be measured. The combination of phosphor and photocell which generates the alpha signal is known as a scintillation detector.

B. Two scintillation detectors will be placed outside the case. The signals from these detectors will be fed to a recording station 3000 yards distant, on the Island of Bogon. A permanent record will be obtained by photographing the face of the recording oscilloscope.

Remarks:

The Radiation Division of the Naval Research Laboratory is responsible for four distinct projects (2.1, 2.2, 2.3, and 2.4) of the program entitled "Progress Of The Nuclear Reaction". The work loads imposed by these projects, however, are not separable. As a result, the NRL personnel under Dr. Krause's supervision will devote their efforts to all projects equally. In lieu of listing personnel requirements for the individual projects, the following table is presented; to represent the total proposed forward area requirements for the above mentioned four projects:

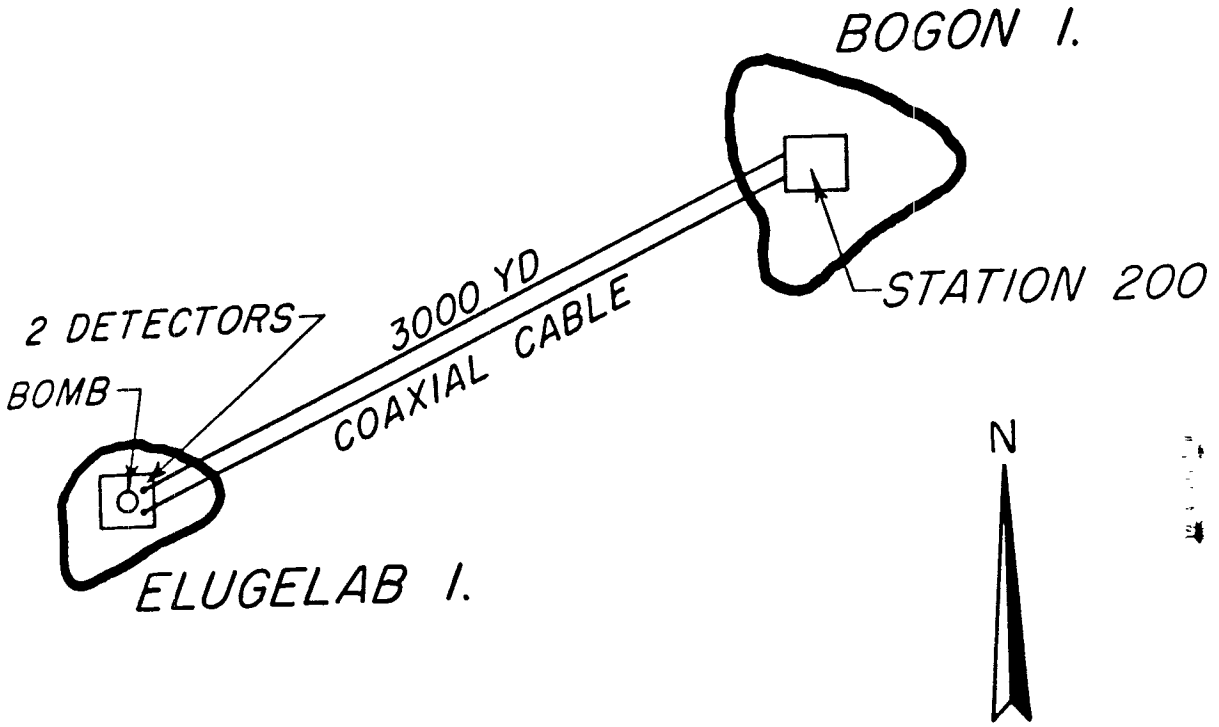
Officer	Enlisted	Civilian	No Name*	From	To
		1		M-153	M-138
		1		M-138	M-67
1	2	8	3	M-123	M-41
		4	2	M-123	M/15
		1		M-108	M-77
		1		M-77	M-16
		2		M-72	M-0
			6	M-72	? **
			29	M-51	? **
		1		M-46	M/15
			10	M-36	? **
	1	1		M-22	M/30

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* As of 16 May 1952, the proper classification (officer, enlisted, or civilian) of these personnel was not known.

** As of 16 May 1952, the date that these personnel will return to the Z.I. could not be estimated with reasonable accuracy.

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(not to scale)

Fig. 2.1a.1
Mike Shot

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PROGRAM 2

PROGRESS OF THE NUCLEAR REACTION

Project No: 2.1b

Project Title: King Alpha

Shot Participation: KING

Sponsor: AEC

Project Officer:

Name: Dr. Ernest H. Krause
Address: Radiation Division
Naval Research Laboratory
Washington 25, D. C.

Phone: Johnson 3-6600
EXT. 684

Conducting Agency: Radiation Division
Naval Research Laboratory

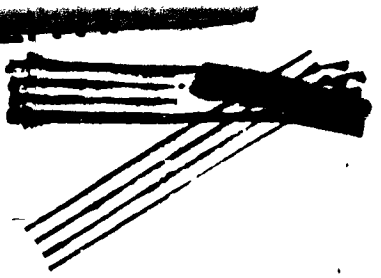
Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* See "Remarks" on page 2.1a.4

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Object of the Experiment:

As was mentioned in the discussion of Project 2.1a, the measurement of alpha is a classical diagnostic experiment for fission weapons. Since the KING shot device is designed to exhibit heretofore unobtainable efficiency, a reliable and relatively complete alpha-versus-time measurement is particularly important to theoretical people in the field of weapon design.

Method and Procedure:

A. The method used herein is identical in principle to that outlined for Project 2.1a. An air drop, however, precludes the use of detectors placed near the bomb case. For KING shot, we are also interested in obtaining more of the alpha-versus-time curve than is required for MIKE shot. In particular, we are interested in the gamma intensity-versus-time curve from four or five generations before the break to the peak. The break point is that point at which the slope of the intensity curve starts to decrease. This implies measuring the constant alpha (of the incubation period) for four or five generations - then following the decrease of alpha from that value to zero.

Since a given scintillation detector and recording mechanism has a limited useful range of response to gamma intensity, and since the above mentioned portion of the intensity curve spans a wide range of intensities, a number of detectors must be used. Each detector and recorder combination is arranged to cover a small portion of the desired range - the arrangement being a matter of obtaining desired attenuations, either with lead shielding or physical location. We thus have a method for documenting the entire gamma-ray intensity-versus-time curve, as follows:

(a) For the early-time low-intensity portion of the curve, we place our detectors very near the bomb case. The low intensities of the early portion of the curve (many generations before the break) will still be high compared to the minimum detectable signal on the recorder - having been attenuated very little.

(b) For later-time high-intensity portions of the curve, we place our detectors at varying distances from the weapon, the distances being chosen in terms of the intensity range desired and the known air attenuation of gamma rays. The recorder may indicate a signal of the same strength as before, but correcting the signal for both air and distance

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attenuations will indicate that such a recorder deflection was caused by a signal of considerably greater intensity. If it is desired to cover two intensity ranges at one distance, one of the detectors can either be surrounded with a lead shield to achieve more known attenuation or be recorded with a lessened sensitivity.

A difficulty is inherent in the method we have outlined, however. Our arrangement of detectors to "see" various intensity ranges has involved only attenuations - that is, we started near the bomb and moved away. What do we do when our nearest available detector position is already far from the bomb - as in the case of a high air drop? The answer there is clear; either we amplify the attenuated signal somehow, or lose the early-time low-intensity portion of the record. Such amplification techniques are being developed, and a feasibility test was conducted quite recently at the Nevada Test Site - they are not sufficiently reliable as yet, however, to warrant depending upon them to furnish the very important KING shot alpha record. We now see why KING shot is being fired at such a low altitude (1500 - 2000 feet), when effects measurements would be greatly facilitated (especially from the viewpoint of tactical use) by its being a much higher (5000 - 6000 feet) burst.

B. The bomb will be fired at some 5700 feet north of station 250 on Runit, at the altitude prescribed above. Two detectors will be placed on the north end of Runit, and their signals will be piped through three inch coaxial cable to recorders in station 250. Hence the nearest detectors will be some 2000 feet from the bomb, and will start their measurement at approximately five generations before the break. Five or six more detectors will be placed near station 250, in order that the remainder of the intensity curve can be documented. The recorders for the latter will also be in station 250, and various recording sensitivities will be used to prevent gaps in the curve.

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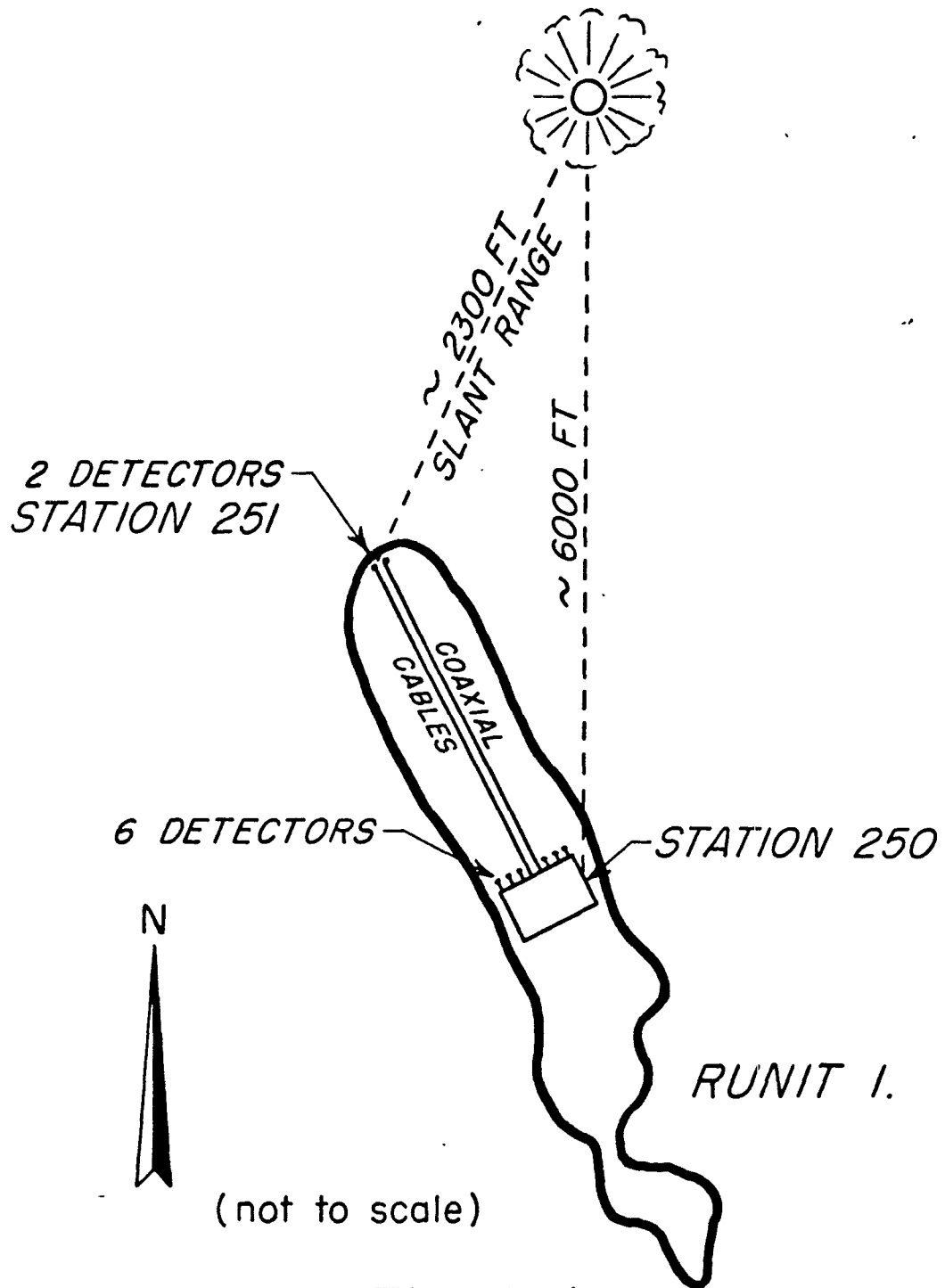


Fig. 2.1b.1
King Shot Alpha

LAWRENCE RADIATION LABORATORY

PROGRAM 2

PROGRESS OF THE NUCLEAR REACTION

Project No: 2.2 Project Title: Timing in the Fission Phase.

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Dr. Ernst H. Krause
Address: Radiation Division
Naval Research Laboratory
Washington 25, D. C.

Phone: Johnson 3-6600
EXT. 864

Conducting Agency: Radiation Division
Naval Research Laboratory

Personnel Requirements in the Forward Area: *

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* See "Remarks" on page 2.1a.4

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Object of the Experiment:

Consistent with the idea of obtaining as much diagnostic information about the thermonuclear reaction as possible, this experiment is designed to determine the timing of the fission phase. Knowledge of this time is important as it tells us whether or not the process took place in the predicted fashion.

Method and Procedure:

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At this writing, the feasibility of detecting primary neutron signals (rather than the secondary neutron-induced gamma ray signals) is being studied. If such a technique is feasible it may be adopted for IVY.

B. The above mentioned signals will be observed directly with scintillation detectors (see discussion of Project 2.1a) at the 3000 yard recording station on Bogon, and indirectly by means of light detectors at Bogon which observe phosphors located on Elugelab. In either case the photocell signal is applied to the vertical deflection plates of a cathode-ray tube in a sweep oscilloscope. The signal which must be applied to the horizontal deflection plate circuit of the tube, the sweep signal, may be obtained from the alpha signal of Project 2.1a (either directly or after having been passed through a fixed-time-delay circuit). The combination of these signals will supply the face of the tube with a trace which can be photographed to obtain a permanent record. In order that these measurements may be time tied to the alpha measurement of Project 2.1a - to obtain the desired elapsed time as our final result - the signal will also be passed through a fixed-time-delay line to a pulse generator, which in turn supplies a "pip" to the vertical

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plates of the tube.* In addition, it is expected that the direct observation detector on Bogon will also see the start of the fission reaction - if so, one record will contain the desired elapsed time without a time-tying requirement.

* Another time-tying technique involves the use of a precision delay (from the alpha signal) circuit. Either or both of these techniques may be used.

PROGRAM 2

PROGRAM 2

PROGRESS OF THE NUCLEAR REACTION

Project No: 2.3

Project Title: Rise of the Fusion Reaction.

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Dr. Ernst H. Krause
Address: Radiation Division
Naval Research Laboratory
Washington 25, D. C.

Phone: Johnson 3-6600
EXT. 864

Conducting Agency: Radiation Division
Naval Research Laboratory

Personnel Requirements in the Forward Area: *

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* See "Remarks" on page 2.1a.4

Object of the Experiment:

This experiment is a continuation of the diagnostic program for the MIKE device. It is designed to document the rise of the fusion reaction, in order that the theory upon which predictions of such phenomena are based may be substantiated.

Method and Procedure:

A. The activation of a chain fusion reaction will imply a flood of high energy neutrons. Many of these neutrons will be captured, and such capture will result in large numbers of high-energy gamma rays being produced. Documentation of these gamma rays will provide data which can be theoretically associated with the progress of the fusion reaction as a function of time. Observation of discrete non-intersecting areas of the case will also furnish information as to the space-wise development of the reaction.

B. A collimating shield will be placed close to the bomb to facilitate observation of small areas of the case. Present thinking conceives the collimator as consisting of two walls; the inner wall being six feet thick, fifteen feet wide, and thirty five feet high, of ordinary concrete, and with its inside face being separated from the case by two feet of air.

The collimated signals will be observed directly by means of scintillation detectors (see discussion of Project 2.1a) at the 3000 yard distant recording station on Bogon, and indirectly by means of light detectors at Bogon which observe phosphors located on Elugelab. As an indication of the electronic complexity of this experiment, let us consider the problems associated with obtaining permanent records of the above mentioned signals. When the fusion reaction takes place, a given signal will have an extremely high maximum value, and be existent for such a short period of time that excellent recording-time resolution is necessary to see it at all. The problem of recording the extreme maximum value of a signal, while retaining sufficient resolution for the detailed study of low magnitude results, is solved by using many scopes - each being adjusted to see only a portion of the total intensity range of the signal.

The signal is impressed on the vertical plate circuit of an oscilloscope, thereby causing a vertical deflection of the electron beam proportional to the impressed signal intensity. A voltage source (of sufficient strength that its "triggering" will cause the electron

beam to traverse the scope face in 2 to 5 microseconds) is available to the horizontal plate circuit. If this horizontal motion occurs at the proper time (when the experiment signal is available at the vertical plates), a two-dimensional trace will be produced on the face of the scope. This trace is a plot of the experiment signal and can be photographed to obtain a permanent record. We thus have introduced the auxiliary problem of triggering the horizontal sweeps at the proper time. This is essential as the sweeps are "one shot" affairs (a periodic sweep would supply a record most difficult of interpretation). The method of doing this is to trigger the horizontal plate voltage source with the experiment signal itself - then pass the experiment signal through a fixed-time-delay loop before impressing it on the vertical plates. However, this method has a serious drawback under certain conditions as we shall see below.

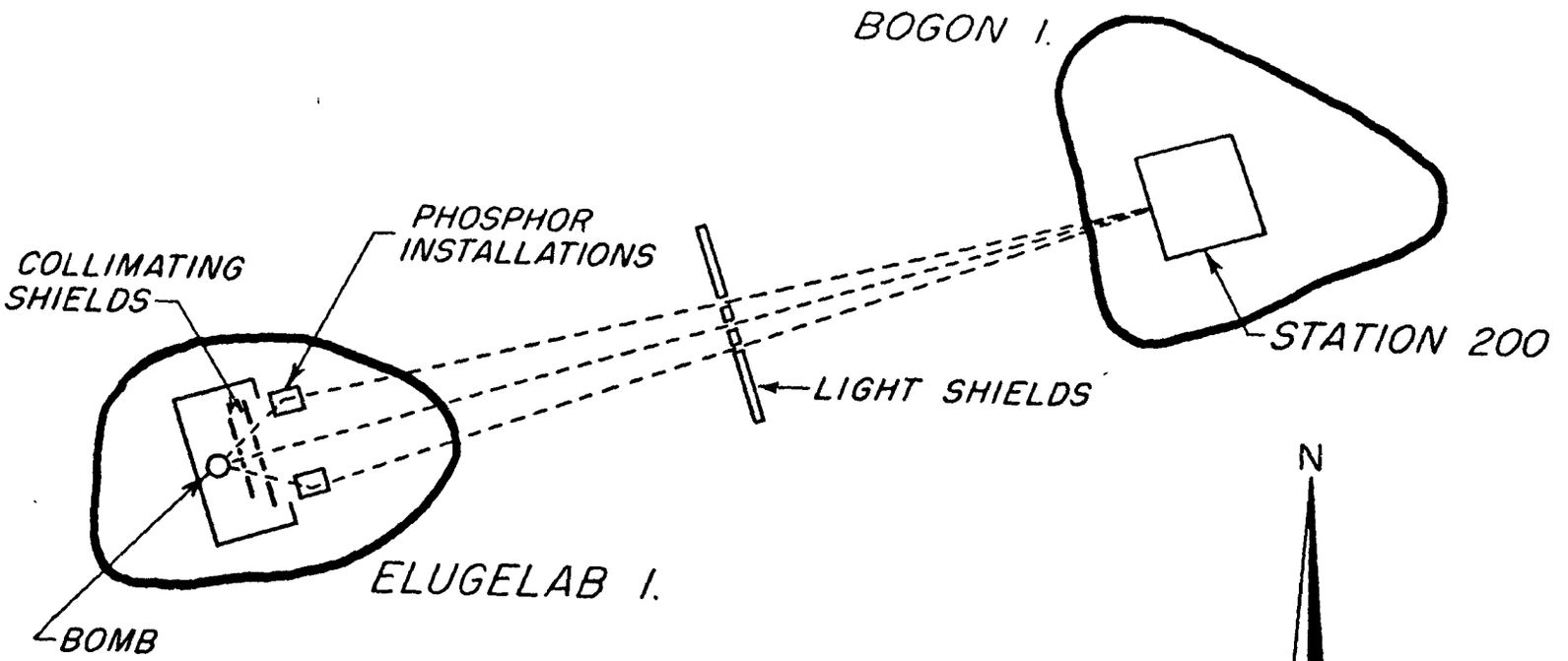
A qualitative picture of the over-all gamma-ray-induced signal from the device must now be considered. The fission phase will cause it to rise to a first maximum, after which it will fall off until the fusion phase starts. The latter burning will cause it to rise to a second maximum (the magnitude of which is determined by the "success" of the fusion process), after which it will fall off to zero. Uncertainties in the theoretical predictions of the magnitude of this signal, in the trough between the maxima, are such that the triggering of the low level scopes by their own signals is not feasible. The scope might be triggered too soon by the high background which follows the first maximum, and the record would be lost. By a low level scope we mean one which has been adjusted to see only the lower portion of the rise to the second maximum for the experiment. High-level scopes present no such problem, and can be triggered by their own signals, since no signal except the correct one can reach the intensities for which these will be set.

The low level scopes will therefore be triggered by passing the initial pulse (rise to initial maximum) through a time-delay circuit. As additional insurance, these low-level scopes may be duplicated, each having a different time delay in the triggering circuit, to take care of uncertainties in theoretical predictions.

The above is of course only a qualitative outline, and only partially indicates the complexities involved. It is presently estimated that four detectors, ten amplifiers and thirty oscilloscopes will be required for this experiment.

Remarks:

As an aid in the interpretation of results, additional "monitoring" observations will be made. For example, one phosphor will be "looking" at the sky, and one photocell will be observing an empty phosphor mounting.



(not to scale)

Fig. 2.3.1
Mike Shot
Rise of the D-D Reaction

PROGRAM 2

PROGRESS OF THE NUCLEAR REACTION

Project No: 2.4

Project Title: Propagation of the Fusion Reaction.

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Dr. Ernst H. Krause
Address: Radiation Division
Naval Research Laboratory
Washington 25, D. C.

Phone: Johnson 3-6600
EXT. 864

Conducting Agency: Radiation Division
Naval Research Laboratory

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* See "Remarks" on page 2.1a.4

Object of the Experiment:

Consistent with the idea of obtaining a maximum amount of diagnostic information from MIKE shot, this experiment is designed to measure the propagation of the fusion reaction throughout the device.

Method and Procedure:

A. The chain of events which makes these measurement possible is precisely the same as that outlined for Project 2.3.

B. The experimental procedures and the complexities involved herein are essentially the same as those outlined for Project 2.3. In this case, however, the collimation is arranged to observe different portions of the case. At the present time, some four positions are proposed. It appears that the recording oscilloscopes for this measurement can be triggered from the scopes of Project 2.3, since there will be no propagation to observe if the thermonuclear reaction fails. Present estimates indicate that four detectors, sixteen amplifiers, and thirty oscilloscopes will be required.

To insure sufficient collimation (and the absence of "cross talk" between independent signals) on the long-air line between phosphors on Elugelab and their associated photocells on Bogon, some 15 to 25 wooden light shields will be required.

Remarks:

1. Monitoring observations will be made for this experiment in a fashion similar to that mentioned for Project 2.3.

2. It may be possible to detect neutrons directly with the phosphor-photocell combinations, rather than the neutron-induced gamma rays. Such a technique is desirable, since it involves observation of the primary signal. Feasibility studies along these lines are being conducted at present.

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PROGRAM 2

PROGRESS OF THE NUCLEAR REACTION

Project No: 2.5 Project Title: Measurement of Transit Time

Shot Participation: KING

Sponsor: AEC

Project Officer:

Name: Mr. C. B. McCampbell
Address: Code 5225-1
Sandia Corporation
Sandia Base
Albuquerque, New Mexico
Phone: Albuquerque 6-4411
EXT. 2-3215

Conducting Agency: Weapons Performance Division
Sandia Corporation

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	4	K-21	K+7
Enlisted			
Civilian	4	K-21	K+7

Support Required:

51

Object of the Experiment:

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Method and Procedure:

A. The initial time pulse for transit time measurement is obtained electrically from the detonator firing system. The second, or terminal, pulse is obtained by detection of the initial flood of gamma radiation from the bomb.

B. For air drops such as KING shot, 2 small radio transmitters are installed within the ballistic case of the weapon. The signals from these transmitters are monitored by 4 receivers, two located in each of two aircraft which accompany the dropping plane. The signals are keyed by the electrical impulse which fires the detonators - thus supplying the initial time to the receivers. The flood of gamma radiation, which accompanies the start of the nuclear reaction, ionizes the air around the bomb and hence makes the transmission of radio signals impossible. Hence a phenomenon (namely, the interruption of a signal) is observable at the receivers to indicate the end of the transit time period. Both of these signal perturbations (the pulse and the interruption) are supplied to the vertical deflection plates of an oscilloscope. A time index is supplied to the scope by a horizontal sweep similar to that used in television receivers, upon which is

52

superimposed, by pulsing the vertical deflection plate circuit, a series of equally spaced (microsecond intervals) timing pips. The duration of the sweep is such as to include all reasonable transit time values for the weapon, and the sweep is triggered by the initial pulse. We thus obtain an oscillograph of the phenomena, which can be photographed for permanent record, with a built-in time scale.

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(not to scale)

Fig. 2.5.1

King Shot Measurement of Transit Time

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PROGRAM 3

SCIENTIFIC PHOTOGRAPHY

Project No: 3.1 Project Title: Ball-of-Fire Yield

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Mr. Herbert E. Grier
Address: Edgerton, Germeshausen, & Grier, Inc.
160 Brookline Avenue
Boston 15, Mass.

Phone: Copley 7-3520 (Office)
Bigelow 4-4956 (Home)

Conducting Agency: Edgerton, Germeshausen, & Grier, Inc.
160 Brookline Avenue
Boston 15, Massachusetts

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	2	M-28	K-7

Support Required: Deck installation (on "Curtiss") of trailer type photographic laboratory.

* See note under "Remarks".

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[redacted]

Object of the Experiment:

One of the basic requirements for any experimental program involving the detonation of an atomic weapon is the determination of whether or not the weapon behaved as predicted - and if not, why not. For fission weapons, the classical method of meeting this requirement has been to conduct a trio of so-called "diagnostic" experiments - the purpose of which was to determine the alpha (α), transit time (τ), and yield (W), of the weapon is question.

At this writing, the only available "absolute"* methods of determining yield are those which involve radiochemical analysis of bomb debris. The existence of hydrodynamical scaling laws, however, has made several "relative" methods of yield measurement available to us. One of these makes use of the fireball diameter at early times. By a relative method we mean one which gives as its result a number which is proportional to the yield. In this case the magnitude of the proportionality factor must be deduced from comparisons of fireball photography results with results of radiochemical analysis methods. Such comparisons have been made on previous experimental programs, with the result that the above mentioned proportionality factor is well established for yields up to 100 KT. [redacted] The IVY program will serve to supply more evidence in higher yield ranges.

The advantage of having complete and reliable information as to the size of this factor over as wide a range of yields as possible is clear. Operational use of atomic weapons will undoubtedly make immediate knowledge of weapon yield imperative, which precludes use of the time-consuming laboratory techniques of radiochemical analysis. Also, it may well be unfeasible to collect acceptable bomb debris samples in the face of enemy defenses. Fireball photography is a potentially feasible method for determining weapon yield quickly and under combat conditions. It is also conceivable that the nature of future experimental programs will be such as to preclude acceptance of the logistical problems associated with the collection of bomb debris samples. For such programs, fireball photography is a well established alternate method for determining yield.

* By an absolute method we mean one which gives, as its final result, the yield of the weapon directly - rather than a number proportional to the yield.

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Method and Procedure:

A. The primary data to be obtained from this experiment are photographic records of the early fireball growth. These data will enable film analysts to determine the fireball diameter at certain specified early times. Such information, when combined with existing data on the above mentioned proportionality factor, will give initial estimates of the weapon yield. Later, when the results of radiochemical analysis are available, additional information as to the proper size of the proportionality factor for such yields will be available.

B. For MIKE shot six Eastman (~2000 frames/sec) motion picture cameras will be operated in a fall-out-proofed shelter on Parry island. Because of the earth's curvature, these cameras will obtain yield only in the event of a large energy release. Three additional Eastmans will be operated from Engebi (in shielded boxes on concrete pillars), to enable a yield determination if the energy release is small (50-300KT). A rapatronic (single frame, with very fast exposure, at a definite delayed time after zero) camera will be operated from the photo tower on Parry.

In addition to the above "primary" cameras, the Mitchell (~100 frames/sec) cameras mentioned under Project 3.2 will give some fireball growth data with much less time resolution.

For KING shot, six Eastmans and one Rapatronic will be operated from the photo tower on Parry. Again, additional long-time resolution data will be obtained from the Mitchells of Project 3.2.

Electronic devices will be used to supply the timing marks to the motion picture camera films, and to operate the Rapatronic at the proper time after zero. Theoretically, one picture at a known time after zero is all that is needed. In the past, however, it has been wise to use motion picture cameras, thereby increasing the probability of obtaining a good picture and increasing the accuracy of the final result by allowing an average to be taken over a multitude of results. The Rapatronic is included in the program to allow a yield estimate to be made from one picture, and to test the accuracy of such a "one picture" result.

It is hoped that sufficient reliability can be built into the Rapatronic technique, and that sufficient confidence can be developed for the scaling of its result, to enable the Eastmans to be eventually discarded in favor of the Rapatronic for this measurement. An obvious decrease in the cost and complexity of the experiment would result, and evidence already exists to support the opinion that no accuracy would be sacrificed. In fact, accuracy may be improved be-

[redacted]

cause of:

(a) The simple R-C network used to supply the necessary time delay to the Rapatronic is highly reliable and capable of excellent laboratory calibration, whereas the time at which a given Eastman picture is taken is not easily determined with the same precision.

(b) The short exposure of the Rapatronic "stops" the fireball growth better than the Eastmans, with the result that a given Rapatronic picture is "better" (a clearer record, capable of more accurate measurement) than any one frame of an Eastman film.

We thus see that the inclusion of the Rapatronics in this project constitutes both duplicate coverage and a feasibility test. If the inherent advantages of the Rapatronic technique can be shown to offset the increased statistics offered by the Eastmans, the ultimate experimental goal, (that is, to obtain a maximum of measurement accuracy and reliability with a minimum of effort and complexity) will be closer.

Remarks:

1. It is interesting to note, in the case of MIKE shot, that fireball photography may be forced to assume the role of a primary measurement for the first time. This possibility exists because of the relatively great uncertainties associated with determination of the fusion yield by means of radiochemical analysis. If it does turn out that a fusion yield is unobtainable with radiochemistry, that yield will be obtained by subtracting the radiochemical fission yield from the total yield given by ball-of-fire photography. Such a procedure does not imply high accuracy, because of the large extrapolation required (to determine the proportionality constant required by the ball-of-fire technique) but it does offer an available alternate method.

2. The firm of Edgerton, Germeshausen, and Grier, Inc. is responsible for five distinct projects (3.1, 3.2, 3.5, 3.6, and 3.8) of the Scientific Photography program. The work loads imposed by these projects, however, are not capable of complete separation. Therefore, most of EG&G's personnel will equally devote their efforts to all projects. As a result, only those personnel whose responsibilities are clearly associated with a particular project are listed under the personnel requirement of that project. In addition, eleven civilians will be available in the forward area for support of all five projects, as follows:

Number	From	To
1	M-42	M/2
2	M-42	K/7
1	M-42	K/10
2	M-28	M/10
1	M-28	K/2
4	M-28	K/7

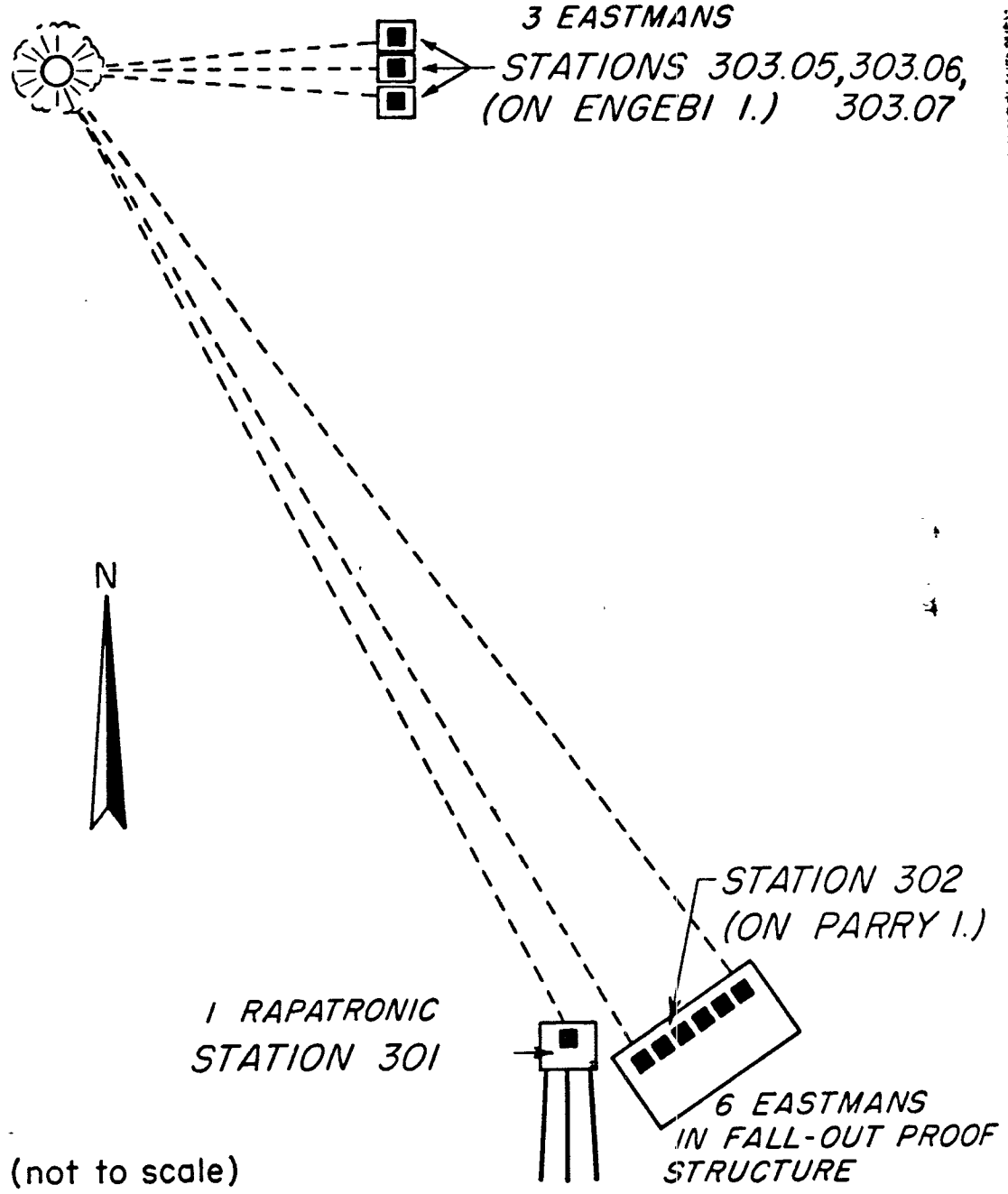


Fig. 3.1.1
Mike Shot Ball-of-Fire Yield

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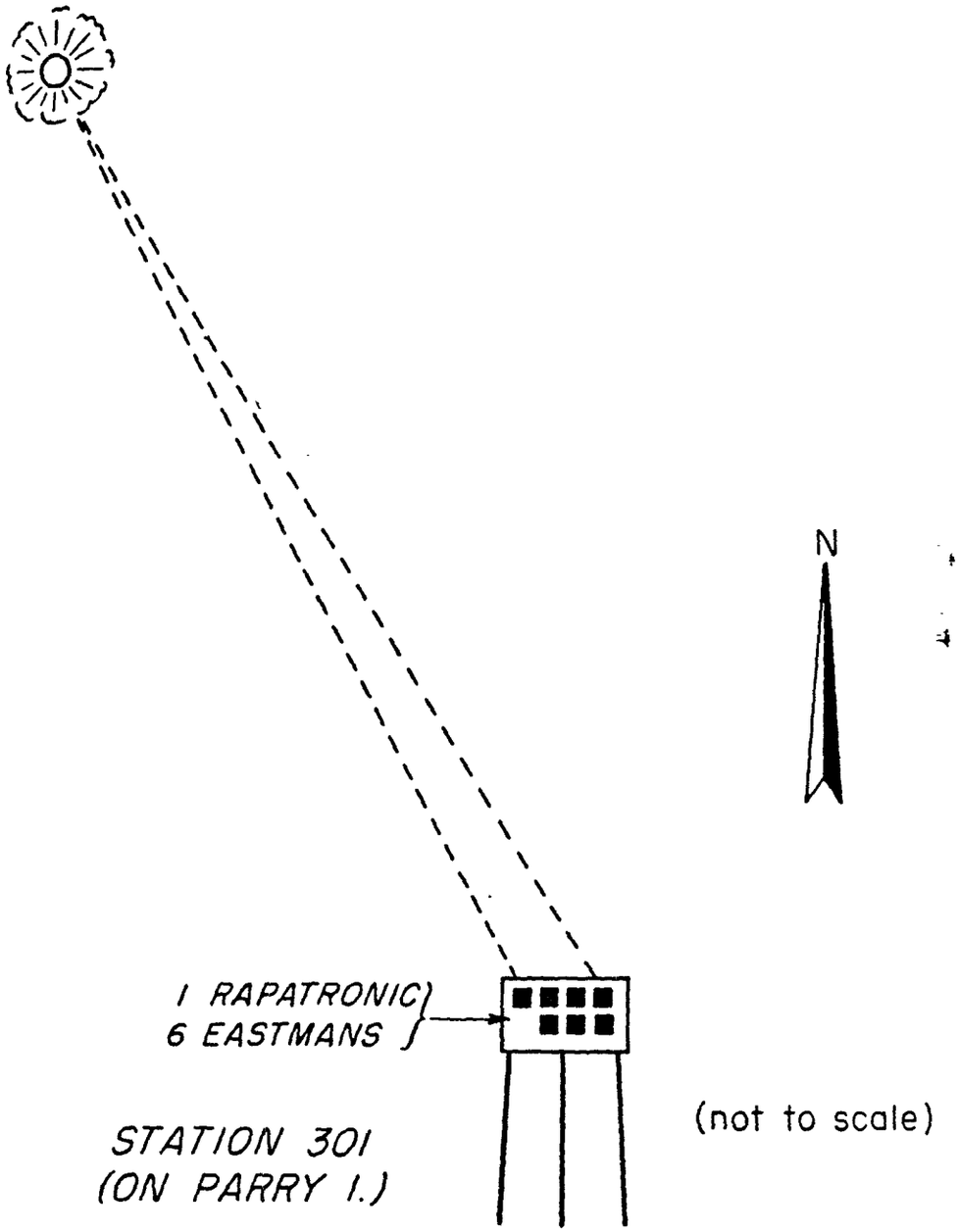


Fig. 3.1.2
King Shot Ball-of-Fire Yield

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PROGRAM 3

SCIENTIFIC PHOTOGRAPHY

Project No: 3.2 Project Title: Cloud Phenomena.

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Mr. Herbert E. Grier
Address: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Mass.

Phone: Copley 7-3520 (Office)
Bigelow 4-4956 (Home)

Conducting Agency: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Massachusetts

Personnel Requirements in the Forward Area: *

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	1	M-28	K+7

Support Required: Deck installation (on "Curtiss") of trailer type photographic laboratory.

* See note under "Remarks" of Project 3.1.

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[redacted]

Object of the Experiment:

To those interested in fallout hazards, tactical bomb delivery planning, or the planning for aerial collection of bomb debris, reliable answers to the following dependent questions are of paramount importance:

(a) What will be the maximum altitude of the top of the cloud, as a function of the yield of the weapon which produced it?

(b) What will be the size and shape of the cloud, as a function of (1) altitude, (2) time after zero, and (3) yield of the weapon?

(c) What is the vertical velocity of the cloud top, as a function of altitude and weapon yield?

Unfortunately the complexity of the physical phenomena involved (for instance, turbulence and mixing) have so far precluded the existence of a theory adequate to answer these questions. It is in fact, most improbable that a complete theory will ever exist. In the face of this fact, two alternative approaches to the problem suggest themselves:

(1) By making radical simplifying assumptions, derive an approximate theory - perhaps keeping one or two adjustable parameters in the result. Then substantiate (if possible) the approximate theory with experimentally observed facts, making whatever parameter adjustment is necessary. If substantiation is impossible, select somewhat different simplifying assumptions and try again.

(2) Using curve fitting techniques, deduce the necessary functional relationships from experimental data. These functional relationships may suggest a simplified theoretical approach of the type mentioned above.

For one to have confidence in predictions or plans based upon the answers to questions (a), (b), and (c) above, both a reasonable approximate theory and experimentally observed facts with which to substantiate a theory must be available. One without the other is interesting and useful, but it does not inspire the user with confidence. In this case we have several approximate theories available, and are lacking in a sufficient amount of good experimental data. The method for obtaining such data is available, and has been used in the past. This method is to take photographs of the cloud throughout the period of its rise to maximum altitude. Prior to BUSTER-JANGLE,

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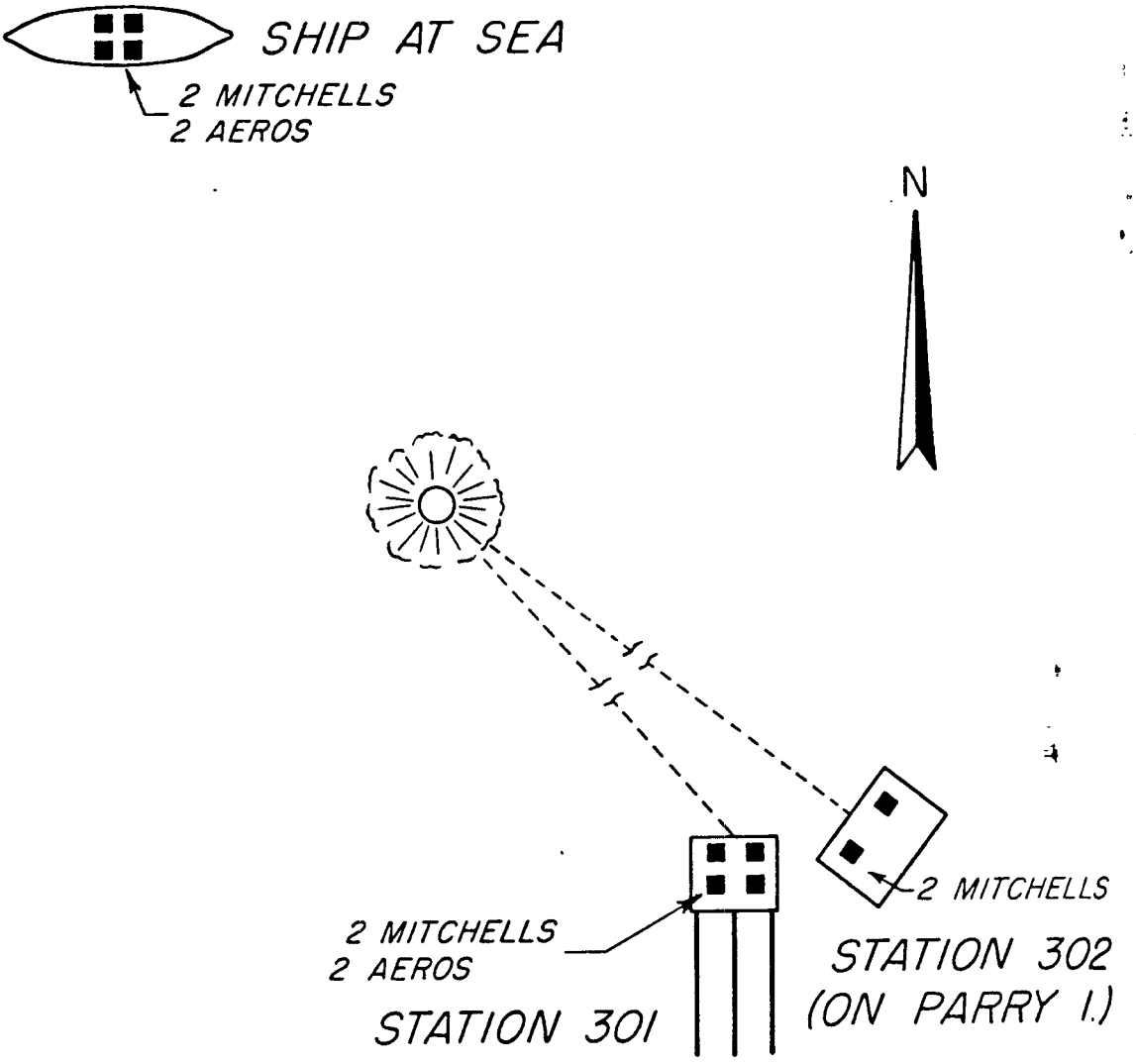
However, such factors as poor lighting conditions, insufficient time resolution of photographic records, and obscuring cloud cover, made it extremely difficult to obtain the required documentation. The IVY cloud phenomena program is designed to extend this search for data, particularly in the high energy release range that is unavailable for all experiments.

Method and Procedure:

A. By obtaining photographs of the cloud, in a known field of view and at known times after zero, film analysis enables a time history to be drawn - not necessarily of the cloud itself, but of the cloud's projection on a plane perpendicular to the axis of the camera. The use of triangulation techniques (several cameras viewing the same phenomena - located on widely separated radial lines from zero), enables the position of the cloud in space to be determined with much greater accuracy.

B. For MIKE shot, eight Mitchell (~100 frames/sec) cameras will be operated - two operated in the fall-out-proofed structure on Parry island, two from the Parry photo tower, two from the photo platform on the Estes, and two from an airplane flying above Kwajalein. In addition, it is planned to operate four aero (~15 frames/sec) cameras - two from the photo tower on Parry, and two from a gyroscopically stabilized platform on the Estes. The cameras on Parry, of course, will be operated by remote control, and will hence obtain their records at the proper time regardless of photographic conditions. (Clouds obscuring the field of view, etc.) The others, however, will probably be hand operated in the hope that on-the-spot selection of exposure periods will enable at least a partial record to be obtained, even in the presence of local cloud cover.

For KING shot, two Mitchell and two Aero cameras will be operated (by remote control) in the Parry photo tower.



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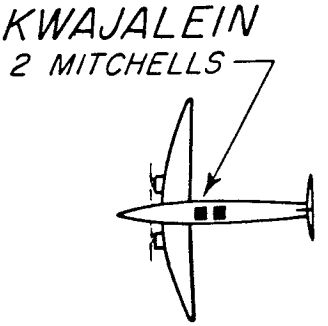


Fig. 3.2.1
Mike Shot
Cloud Rise Photography

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PROGRAM 3

SCIENTIFIC PHOTOGRAPHY

Project No: 3.3 Project Title: Hot-Spot Observation

Joint Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Berlyn Brixner
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-3741

Conducting Agency: Group GMX-9
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-30	K/10
Enlisted			
Civilian	2	M-30	K/10

Support Required:

[redacted] [redacted]

Object of the Experiment:

Laboratory design of a fusion bomb is strongly dependent upon the extraction of as much information as possible from each field experiment. The theoretician is fully as much interested in why a test model behaved as it did, as he is in how it behaved. As a result, the experimental program for MIKE shot includes a relatively large number of diagnostic experiments - each of which is designed to throw some light on the actual chain of events which immediately follow the fission phase. In some cases, completely independent experiments are designed to observe the same phenomenon, either directly or indirectly - thus increasing the probability of obtaining useful results.

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One interesting piece of diagnostic information is the temperatur distribution inside the gadget prior to disassembly, as the relative "success" of a fusion reaction is closely associated with temperature. This experiment is intended to supply some of that information in an indirect fashion.

Method and Procedure:

A. The time necessary for the explosion wave to traverse a known distance in metal is, of course, a direct indication of the speed of the wave. Knowledge of this, plus the known speed of a sound wave in a particular metal, enables one to deduce the "strength" of the explosion wave from hydrodynamic theory. This in turn is theoretically related to the temperature behind the shock wave in that region.

Three selected areas of the gadget case will be observed photographically by six cameras - the field of view of each camera being sufficiently large to include all of the three areas. In each area, two surfaces will be observed; the first being the outer surface of the case itself and the second being the outer surface of a one-inch-thick steel plate attached to the case.

The time difference between shock arrival at these two surfaces will then give the time required for the shock to traverse one inch of steel. The arrival of the wave at an observed surface will be indicated by a sharp rise in the light intensity seen thereon.

B. Six streak (fixed-film, moving image generated by rotating mirror) cameras, each having a time resolution of approximately 3 shakes (1 shake = 10^{-8} seconds), will be operated from a fall-out proofed shelter on Bogallua. The external areas of the gadget case

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[redacted] [redacted]

...ted for observation are (1) Near the top, (2) Just above the ...t, and (3) Near the bottom of the assembly. The light from these ...s will be directed to a line of mirrors angling lagoonward on the ...ian side of zero, and thence reflected to the cameras. All cameras ... have a sufficiently wide field of view to see all mirrors.

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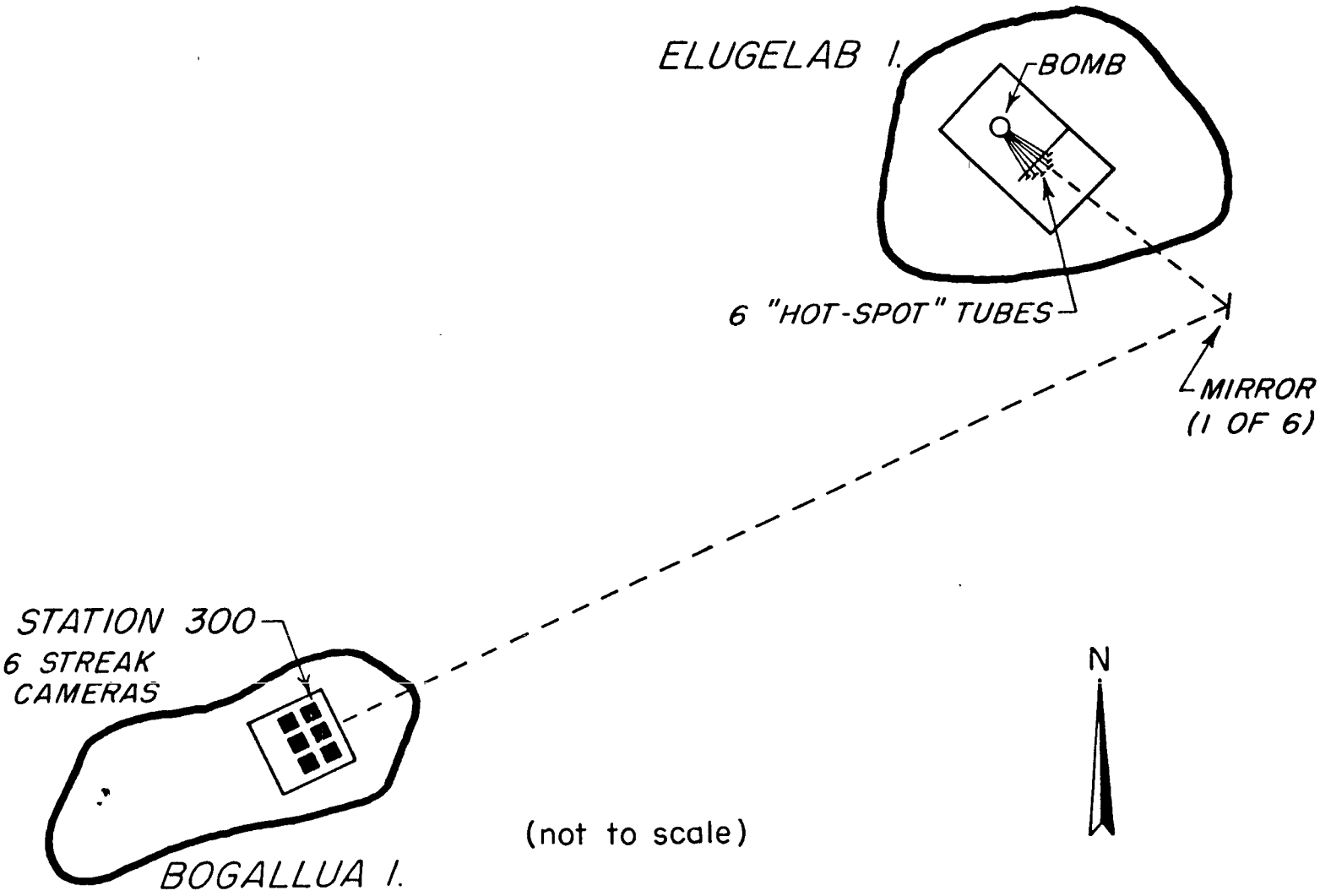
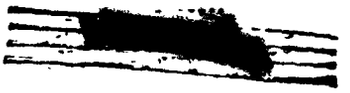


Fig. 3.3.1-
Mike Shot Hot-Spot Observation





PROGRAM 3

SCIENTIFIC PHOTOGRAPHY

Project No: 3.4 Project Title: Bomb Case Motion

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Berlyn Brixner
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-3741

Conducting Agency: Group GMX-9
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted	1	M-30	K/10
Civilian	2	M-30	K/10

Support Required:

Mike Shot Hot-Spot Observation

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Object of the Experiment:

We have seen, in the discussion of Project 3.3, that several sweeping image ("streak") cameras will observe light intensity on the surface of the MIKE gadget case indirectly - by utilizing reflecting mirrors. This experiment is designed to supplement and extend such "early time" documentation by observing the case disassembly and initial fireball growth directly.

A detailed knowledge of how the gadget case disassembled is invaluable to those interested in internal temperatures, pressures, reaction rates, etc. The early formation of "jets" are also of great interest, as they are indicative of non-uniform expansion (or compression) and may explain the existence of temporary assymetries in the shock wave.

Method and Procedure:

A. The case will be observed directly with two groups of 3 cameras, the first group operating at a speed of 3.5 million frames per second and the second group operating at a speed of 90 thousand frames per second. The first group is designed to document the case disassembly, and the slower group will document the initial fireball development. The decreased time resolution of the second group will, of course, imply that records are taken over a longer period of time.

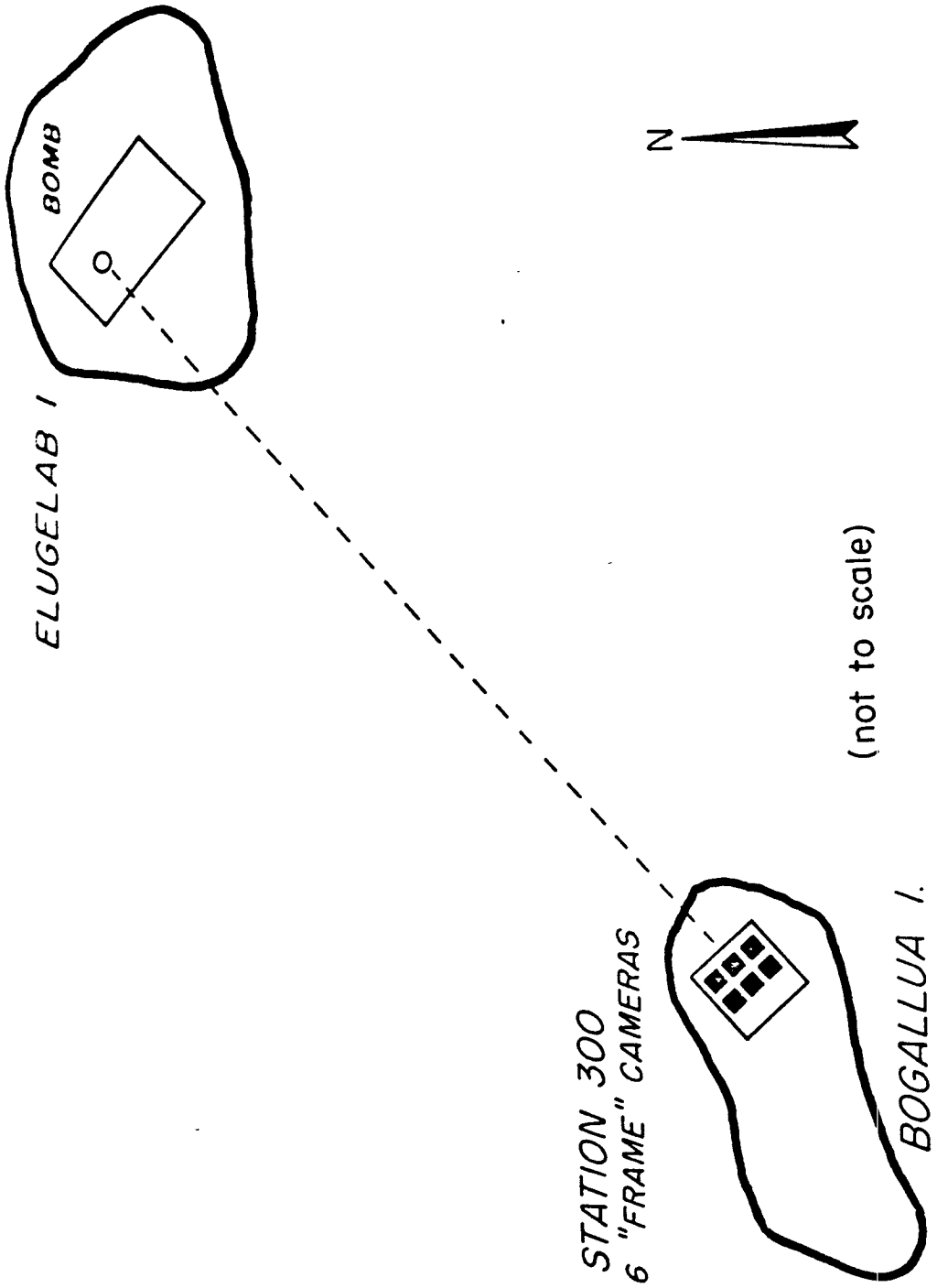
Since these cameras achieve their high time resolution by using the sweeping image technique (fixed film and rotating mirror), electronic timing devices must be used to close the shutters after the film has been swept once. Otherwise, multiple exposure would result. For lack of a better name, these cameras are called "frame" cameras.

B. The six cameras used in this experiment will be housed in a fall-out-proofed shelter on Bogallua - the same shelter as is used by Project 3.3.

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(not to scale)

Fig. 3.4.1

Mike Shot Bomb Case Motion

PROGRAM 3

SCIENTIFIC PHOTOGRAPHY

Project No: 3.5

Project Title: Illumination as a Function of Time, With GR-Slit Cameras.

Joint Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Mr. Herbert E. Grier
Address: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Mass.

Phone: Copley 7-3520 (Office)
Bigelow 4-4956 (Home)

Conducting Agency: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Massachusetts

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer	1	M-42	K/7
Enlisted			
Civilian			

Support Required:

* See note under "Remarks" of Project 3.1.

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Object of the Experiment:

This project is included in the Scientific Photography program to augment the collection of data on illumination as a function of time from exploding atomic weapons. One value of such data is discussed under Project 3.6. Another value is the establishment of a fund of information with which to design and adjust photographic equipment being used under the light conditions generated by atomic bombs. The success of such projects as 6.2 and 6.4a is completely dependent upon good photographic records being obtained - which implies that such things as film sensitivity, shutter speed, and auxiliary lenses (filters) must be selected with great care. Knowledge of the light intensities that will be experienced is essential in making these selections.

Method and Procedure:

A. Perhaps the simplest and most direct technique for measuring overall illumination as a function of time from an atomic bomb explosion is afforded by a device known as the GR (General Radio - the manufacturer) "slit" camera. It consists, essentially, of a rectangular aperture in front of a moving photographic film. The aperture is covered with a strip of neutral density (ND) filter material* - the strip being constructed in such a way as to make available a wide selection of ND filters. That is, as the aperture is traversed, a small section is covered with an ND-0 filter** - the next small section is covered with an ND-1 filter, and so on. The net result is that the photographic record will consist of a series of parallel streaks (dark lines) on the negative. Each streak will have been made by the bomb light; attenuated a known amount by the ND filter in front of that portion of the film. Some of the streaks will be completely overexposed (or underexposed) over a portion of their length. The multiplicity of the filtering available insures us that an adequate readable record can be found somewhere on the film, even if the bomb light deviates strongly from prognostications.

* A neutral density filter is one which is not color sensitive - that is, it attenuates all visible light by the same amount.

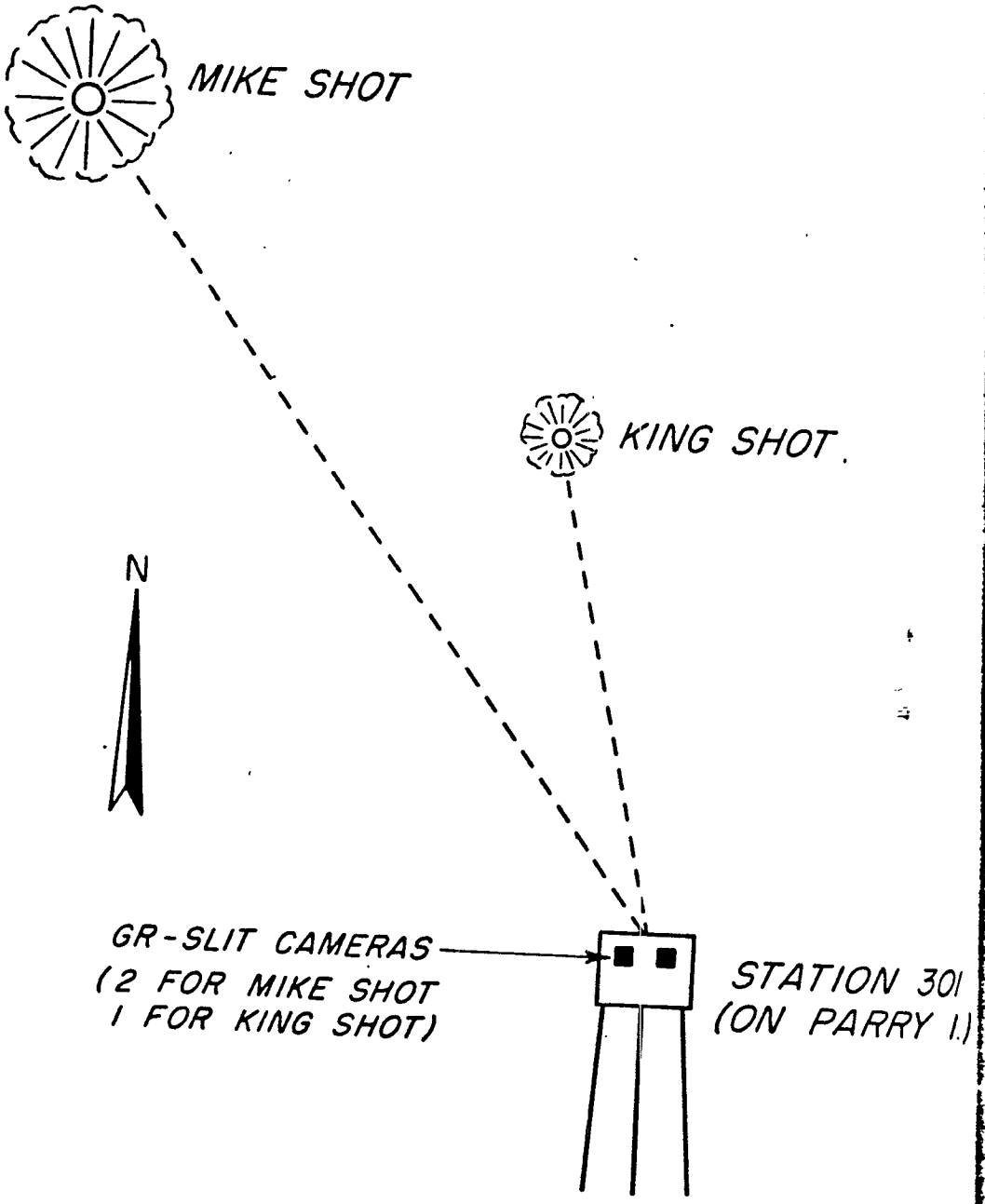
** An ND-0 filter attenuates the light not at all. An ND-1 filter attenuates the light by a factor of 10. In general, an ND-X filter attenuates the light by a factor of 10^X.

The density (opaqueness) of a streak at a given point along its length can be determined in the laboratory with a densitometer, and this is a measure of the light intensity falling on the film at the time that point was opposite the aperture. By multiplying this light intensity by an appropriate factor (determined by the filter), one obtains the bomb light intensity at that time. By combining the above information with the known starting time and linear velocity of the film, one can construct the required curve of illumination-intensity versus time.

B. For MIKE shot, two GR-Slit cameras will be operated on the Parry island photo tower.

For KING shot, one GR-Slit camera will be operated on the Parry tower.

In each case, the cameras will be started by means of an electrical pulse (timing signal) supplied by EG&G.



(not to scale)

Fig. 3.5.1
Illumination as a Function of Time
for Mike and King Shots

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PROGRAM 3

SCIENTIFIC PHOTOGRAPHY

Project No: 3.6 Project Title: Ehangmeters

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Mr. Herbert E. Grier
Address: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Mass.

Phone: Copley 7-3520 (Office)
Bigelow 4-4956 (Home)

Conducting Agency: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Massachusetts

Personnel Requirements in the Forward Area: *

	Approximate Number	From	To
Officer			
Enlisted	1	M-42	K-7
Civilian			

Support Required:

* See note under "Remarks" of Project 3.1

Object of the Experiment:

As was mentioned in the discussion of Project 3.1, there exists a definite requirement for a device capable of measuring weapon yield during tactical operations. Ideally, such a device will be:

(a) Small, light, and self-contained.

(b) Sufficiently rugged to withstand normal operational use without impairment of its operation or accuracy.

(c) Capable of being operated by its user at a relatively great distance from the explosion.

(d) Capable of supplying its user with a yield number in a minimum of time.

(e) Simple to operate.

The Bhangmeter represents an attempt to develop such an ideal device. In its present form it is a steel box; eighteen inches long, twelve inches wide, and five inches deep - weighing approximately thirty pounds.

The theory behind its operation can be described as follows: The light intensity emanated from an atomic bomb explosion first rises to a maximum with extreme rapidity. It then falls quite rapidly to a minimum and rises again, somewhat less rapidly, to a second maximum, the magnitude of the second maximum being very much less than that of the first. After passing through the second maximum, it falls off rather gradually (on a millisecond time scale) to background values.

If one assumes that the first minimum is indicative of a mathematical "similarity"* condition, it is simple to show by means of hydrodynamic theory that the weapon yield is proportional to the cube of the elapsed time between zero and the occurrence of the first minimum. Conversely, to the extent that the first minimum is not indicative of a similarity state, the so-called "cube-root" scaling law will fail to hold. Also, analysis of the equations involved tells us that no true scaling law other than the above mentioned cube root law is possible. We are thus faced with the following alternatives.

* For a precise definition of similarity, the reader is referred to the Project Officer. For our purposes it will be sufficient to consider the term as meaning "the same, except for a constant factor throughout."

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(a) The first light minimum does label a state of actual similarity - therefore, the cube root scaling law must hold absolutely.

(b) The first light minimum does not label a similarity state at all - therefore no true scaling law exists.

The results of past experimental work are inconclusive. A large percentage of the experimentally determined light-minimum times give yield numbers within ten percent (the accuracy claimed for the Bhangmeter itself is 20%) of radiochemistry - a few do not. It is not felt however that case (a) has been completely denied as a possibility as there is a strong indication of color sensitivity in the light-intensity-measuring devices used. Careful laboratory analysis is indicated before final conclusions can be drawn. On the other hand, it appears that a rather good empirical fit can be made with past data by using something other than the cube root law. At first this may seem contradictory to both case (a) and (b); actually it is not. Case (b) does not deny the existence of any number of empirically determined scaling methods - it says only that no true law exists. A scaling law implies the invariance of a differential equation (or equations) under a given transformation- an empirically determined scaling method implies nothing but itself regardless of how useful it may be. Hence neither case (a) nor case (b) have been denied or substantiated.

Our problem then consists of continuing the development and calibration of the Bhangmeter, plus attempting to absolve anomalies in past (and perhaps future) data in such a way that either case (a) or case (b) above will be substantiated - and, if case (b) is substantiated, to find the best empirically determined scaling method available. Future users of the Bhangmeter will care little about the type of scaling used - as long as the results are sufficiently accurate (± 10%, probably) and dependable.

The inclusion of this project in Operation IVY will augment the above mentioned calibration, and hence continue what might be called the Bhangmeter feasibility studies, especially in the relatively high yield range.

Method and Procedure:

A. The Bhangmeter obtains the above mentioned elapsed time to first minimum for its user in the following fashion: A light-sensitive electronic valve observes the bomb light, the amount of current passing through the valve being proportional to the intensity of the light it sees. This current is used to deflect the sweep in a cathode ray tube so that a picture of the light intensity curve is drawn

on the retentive fluorescent screen of the tube. A Polaroid "Land Camera" photographs this picture and hence provides a permanent record. An electronic timer which interrupts the cathode ray tube sweep momentarily every millisecond is included, so the picture is made up of a series of dots rather than a continuous line The elapsed time is then obtained by counting the dots from the start of the curve to the minimum.

B. For MIKE shot, one Bhangmeter will be installed on the Parry island photo tower, and another will be installed on the "Estes". In addition, others may be placed at more distant stations.

For KING shot, Bhangmeters will be installed on the Parry island photo tower.

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PROGRAM 3

SCIENTIFIC PHOTOGRAPHY

Project No: 3.7

Project Title: Preliminary Photographic Crater Survey.

Shot Participation: MIKE

Sponsor: DOD (USAF)

Project Officer:

Name: Lt. Col. James L. Gaylord
Address: Lookout Mountain Laboratory
8935 Wonderland Avenue
Hollywood, California

Phone: Hudson 2-1261

Conducting Agency: USAF Lookout Mountain Laboratory and Air Research and Development Command

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required: Part time use of the B-29 assigned to Documentary Photography coverage.

* Personnel for this Project are included in Task Unit 9 (Documentary Photography).

Object of the Experiment:

To obtain a preliminary photographic survey of the crater caused by MIKE shot, for use in the study of earth shock. It is also hoped that a correlation can be established between photographic evidence of surface perturbations and the fraction of the bomb's energy release that is "coupled" with the ground. Experience on previous tests has shown that early ground surveys of the crater are precluded by radiological hazards.

Method and Procedure:

A. A number of accurately surveyed ground points will be established close to Elugelab Island, with adequate marking of these points to assure contrast and definition when photographed. These positions must be so selected as to be easily distinguishable after the shot as well as before. Precise location of ground zero in relation to these positions is essential, and sufficient aerial photography of the shot island and adjacent islands prior to the explosion is planned to confirm the ground control.

B. The preliminary survey will be conducted from aircraft with vertical cameras as soon as practicable after the explosion of the MIKE device. The still cameras mounted in the documentary photography aircraft will be used only for oblique coverage on this project. Efforts will be made to obtain vertical and/or vertical stereoscopic photographs which will yield information on the size of the crater and the height of the material thrown out around the crater lip. Since considerable time must elapse before the crater can be surveyed in detail by personnel on the site, it is essential that the preliminary photographic survey yield as much data concerning the crater as is possible.

Remarks:

The experience of a similar project on Operation GREENHOUSE indicates that this photography should be done from an altitude of not less than 1000 feet. It was also found advantageous to process the film as soon as possible after the mission, in order that new photographs could be obtained in the event of equipment malfunction.

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PROGRAM 3

SCIENTIFIC PHOTOGRAPHY

Project No: 3.8 Project Title: Burst Position.

Unit Participation: KING

Sponsor: AEC

Project Officer:

Name: Mr. Herbert E. Grier
Address: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Mass.

Phone: Copley 7-3520 (Office)
Bigelow 4-4956 (Home)

Conducting Agency: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Massachusetts

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	1	M-42	K+7

Support Required:

* See note under "Remarks" of Project 3.1.

[redacted]

85

Object of the Experiment:

Experimental air bursts, such as KING shot, impose the unique problem of determining their actual burst position in space. Prior to the shot, of course, a ground zero is selected and the detonation mechanism of the bomb is set for a given height of burst. The combination of bombing inaccuracy and the inherent inaccuracies of the detonation mechanism, however, make it extremely unlikely that the burst will actually take place at the preselected point in space. On the other hand, the success of many experimental projects is dependent upon knowing the bomb zero point with good accuracy. As a result, a rather precise photographic technique is used to locate the position (in space) of the light flash which characterizes the exploding bomb.

Method and Procedure:

A. Once the procedure for conducting this project is outlined, the details of the experimental method are obvious - hence we shall proceed directly to a discussion of the procedure.

B. The proposed bomb zero point is 1500 feet above the ground and 5700 feet due north of station 250 on Runit island. The region in space which includes this point will be observed photographically by two survey cameras, one located on Coral Head and one located in the Parry island photo tower. In addition to seeing the light flash from the exploding bomb, each camera will see two fixed points - the positions of which (with respect to the camera) are known with great accuracy. The distance between the images of these points on the film supplies the film analyst with a simple and accurate distance scale, with which to locate the burst point with respect to the fixed points. Measurement of a given film will then locate the burst point in a plane perpendicular to the axis of the camera - and having two such location planes will allow the burst point to be located in space.

The success of this project depends upon accurate information as to the camera positions, as well as the positions of the above mentioned fixed points, hence very precise surveying techniques are essential. Images of the fixed calibration points are obtained on the films by time-exposure, the night before the shot, to lights located at those points. The films in these cameras are actually glass plates, since the experimental error would be increased by the shrinkage of ordinary film. The image of the bursting bomb is obtained as a small dark spot on the negative (and hence the measurement errors

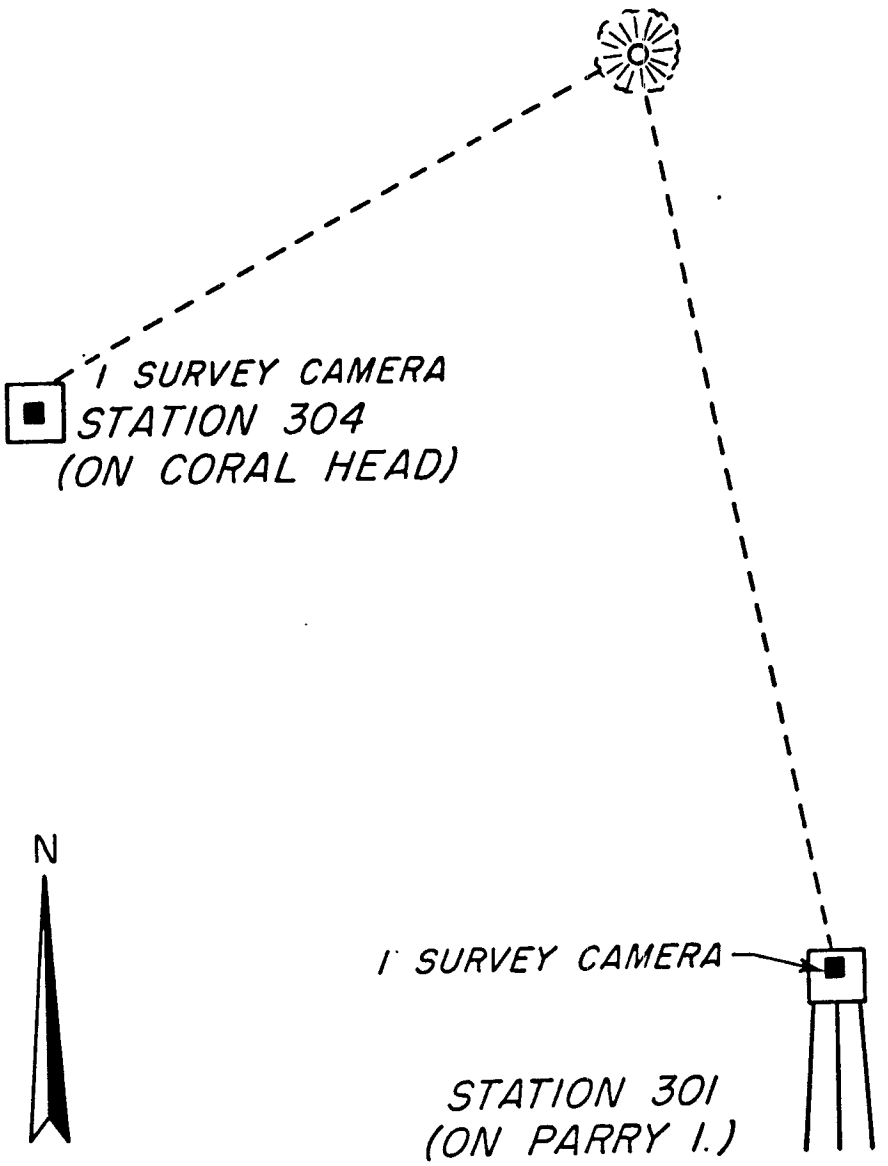
are reduced) by greatly attenuating the bomb light with a strong ND filter (on the order of ND-9).*

Remarks:

1. The closer to proposed zero the bomb bursts, the more accurate is the location technique outlined above. This is because of the method used to obtain a distance scale on the film plate. The distance scale will be in error to the extent that the actual burst point is more or less distant from the camera than the fixed calibration points. The usual bombing error, however, is so small compared to the distance from zero to the camera that this effect is negligible.

* See the footnotes to the discussion of Project 3.5.

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(not to scale)

Fig. 3.8.1
King Shot Burst Position

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PROGRAM 4

NEUTRON MEASUREMENTS

Project No: 4.1 Project Title: Slow Neutron Observation.

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. Clyde L. Cowan
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2844
7-4000

Conducting Agency: Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	2	M-35	K/1

Support Required:

Object of the Experiment:

The flood of neutrons which emanate from an exploding atomic device is of great interest to workers in at least two independent fields - that of bomb design (and the associated diagnosis of bomb performance) and that of "effects on things" (materials and animals, in particular). The neutron measurements program of Operation IVY is designed to augment existing data on neutrons and to continue the development of field measurement techniques - in order that the ultimate goal of complete documentation of neutron economy will be closer. In addition, especially for MIKE shot, it is designed to supply diagnostic information as to the "modus operandi" of the device.

In part, one is interested in the distribution of neutrons with respect to time, distance, and energy. Knowledge of the time dependence is primarily a theoretical requisite, but knowledge of the distance and energy dependence is as important to the soldier in the field as it is to the scientist. The neutron intensity-versus-distance curve tells us the lethal range of a neutron, and the energy spectrum at a given distance tells us the amount of shielding necessary for protection - not only of men, but of critical materials.

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If one knew the total number of neutrons emitted by an atomic bomb at explosion time, and the energy of each, neutron diffusion theory could be used to compute the subsequent neutron "field", with respect to both distance and time. In essence, such knowledge would supply the "initial conditions" for a set of integro-differential equations - and relatively straight-forward theoretical techniques could be used from there on.

Unfortunately these initial conditions are not known, and the problem must be approached in reverse. By making various measurements in the neutron field, one attempts to gain sufficient information for a deduction of "what the initial conditions must have been".

Every neutron liberated by an atomic bomb is ultimately captured by some element in the surrounding medium (air, ground, etc.) Some will be captured before losing any of their energy - others will be

[redacted]

[redacted] only after losing some portion of their energy in one or more [redacted]. As a result, the existence of a neutron having energy E at a distance R from the bomb can indicate at least two possibilities:

(a) It may have left the bomb with energy E and traversed the distance R unmolested.

(b) It may have left the bomb with some energy greater than E and had its energy reduced by one or more collisions while traversing the distance R.

Each of these possibilities is associated with a definite probability of occurrence. Hence if one measures the total number of such [redacted] (energy E at distance R), diffusion theory can be applied in reverse to indicate their probable ancestry at the bomb. A multiplicity of such measurements taken at different distances and for different neutron energies allow one to build a more complete, as well as consistent, [redacted] of the above mentioned "initial conditions".

This project is part of a continuing program to determine the [redacted] distribution of low energy neutrons liberated by various sizes and types of atomic bombs.

[redacted] and Procedure:

A. Neutrons of energy in the range from thermal* to .25 electron volts (EV)** are essentially all captured by the element cadmium. Also, cadmium is quite transparent to neutrons of energy greater than .25 EV. These facts enable us to design a "target" which, when bombarded with neutrons of many energies, is capable of measuring the number of those neutrons in the energy range from .025 to .25 EV.

First we select an element which, upon being bombarded with neutrons, produces a radioactive by-product. Ideally, the element selected should be inert with respect to gamma radiation and the by-product should have a sufficiently long half-life to be amenable to laboratory analysis (counting) techniques. Two samples of this element are then prepared - one being coated with cadmium and the other left pure. These samples are together exposed to the neutron bombardment and subsequently placed in "counters" which measure the induced activity.

* Thermal neutrons are those with energies of the order of .025 EV.

** 1 EV = 1.602×10^{-12} ergs.

[redacted]

[redacted]

The difference in the induced activities of the two samples is then the amount of activity induced in the selected element by neutrons of energy in the range .025 EV to 0.25 EV. (This is usually referred to as the "cadmium difference"). Laboratory calibration of the element with neutrons of a known energy (for instance, as can be obtained with a Betatron) will then allow this cadmium difference to be interpreted in terms of numbers of neutrons (in the above mentioned energy range) striking a square centimeter of area of the "target" element.

This, in turn, finally allows one to deduce the total number of those neutrons which are existent (integral over time) at a given distance (the distance from zero at which the samples were exposed) from the particular bomb detonation. Such a measurement can be repeated at several distances to obtain an intensity-versus-distance curve for those neutrons.

The method outlined above is used in this project, the selected target elements being tantalum and gold.

B. For MIKE shot, pairs of tantalum and gold samples (one of each being shielded with cadmium at each station) will be placed on a line extending along the reef toward Bogallua. The first pair will be 100 yards from zero, and a pair will be placed every 100 yards from there to 2500 yards. Two sample recovery techniques have been proposed - one being to fasten the samples to a steel cable which can be hauled in after the shot; the other being to place the samples on fixed individual pylons and retrieve them after the shot by helicopter. In all probability, a combination of these methods will be used. After recovery, the samples will be shipped to Los Alamos for laboratory analysis.

For KING shot, the same technique will be used. The line of samples will start on the reef (300 feet from proposed ground zero) and extend down the center of Runit island to the region of the airstrip (7200 feet from proposed ground zero).

Remarks:

1. The samples must be collected as soon as possible after the shot, in order that the radioactive by-products will not decay any more than is absolutely necessary before laboratory analysis can be done. Also the near (to zero) sample containers are usually in extremely "hot" (radioactivity-wise) areas and may be "hot" themselves. Hence the recovery problems of this project are potentially very severe.

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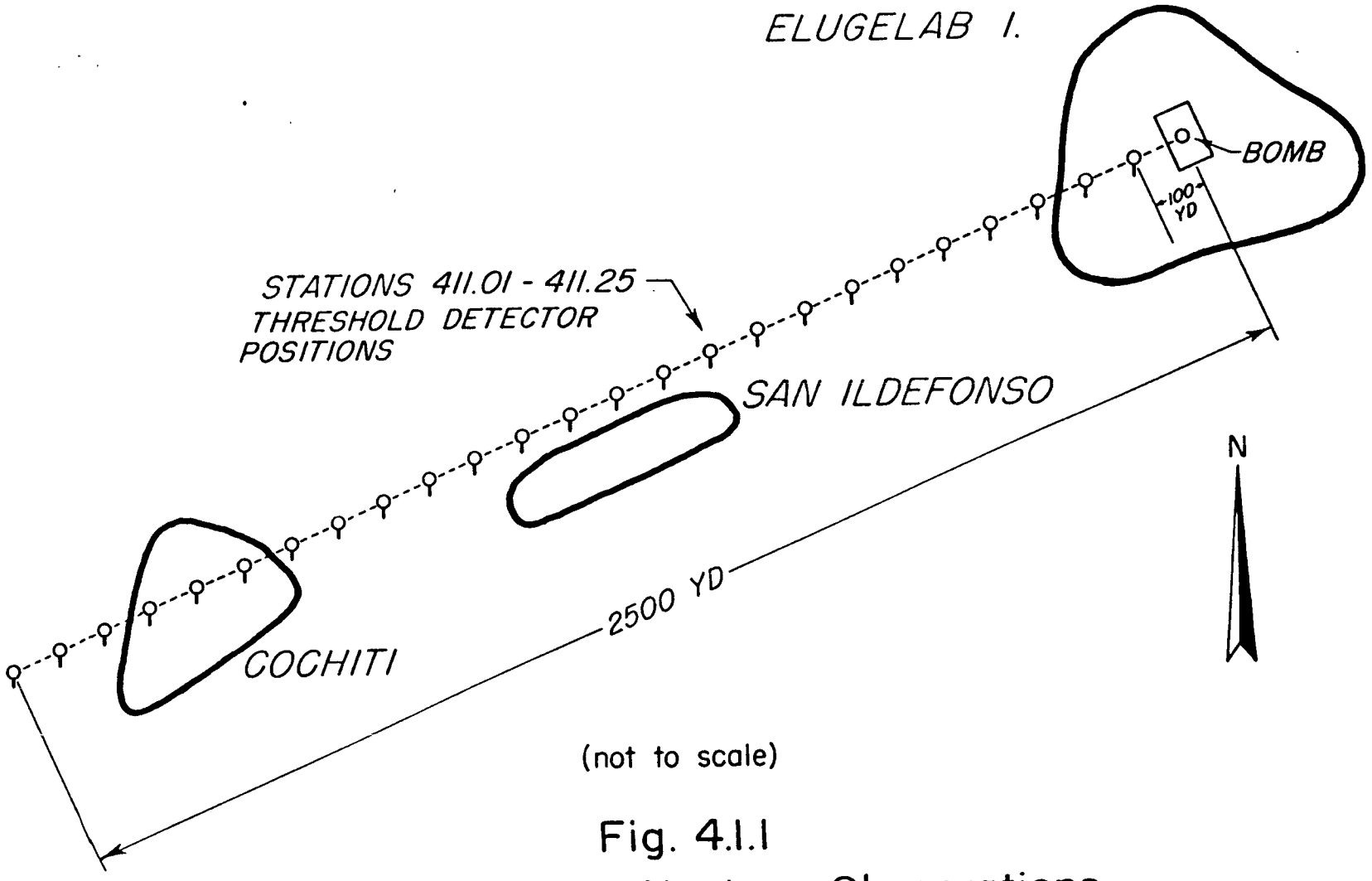
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2. The above outlined technique only allows deduction of the [illegible] of neutrons in a very limited energy range. For the theoretical "inverse approach" to be of appreciable value, measurements must be made in other energy ranges, so that a much greater percentage of the total ancestor distribution can be deduced. Project 4.2 is devoted to such measurements for energies greater than 3 million electron volts (MEV). A secondary objective of this project will involve attempts to document energies between .25 EV and 3 MEV. The techniques required for such measurements are not yet proven, so this portion of the experiment is primarily a feasibility study. In particular, it is hoped that the high cross section exhibited by Indium, for neutrons of [illegible] EV, will be useful.

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(not to scale)

Fig. 4.1.1

Mike Shot Slow Neutron Observations

Fig. 4.1.1
Mike Shot Slow Neutron Observations

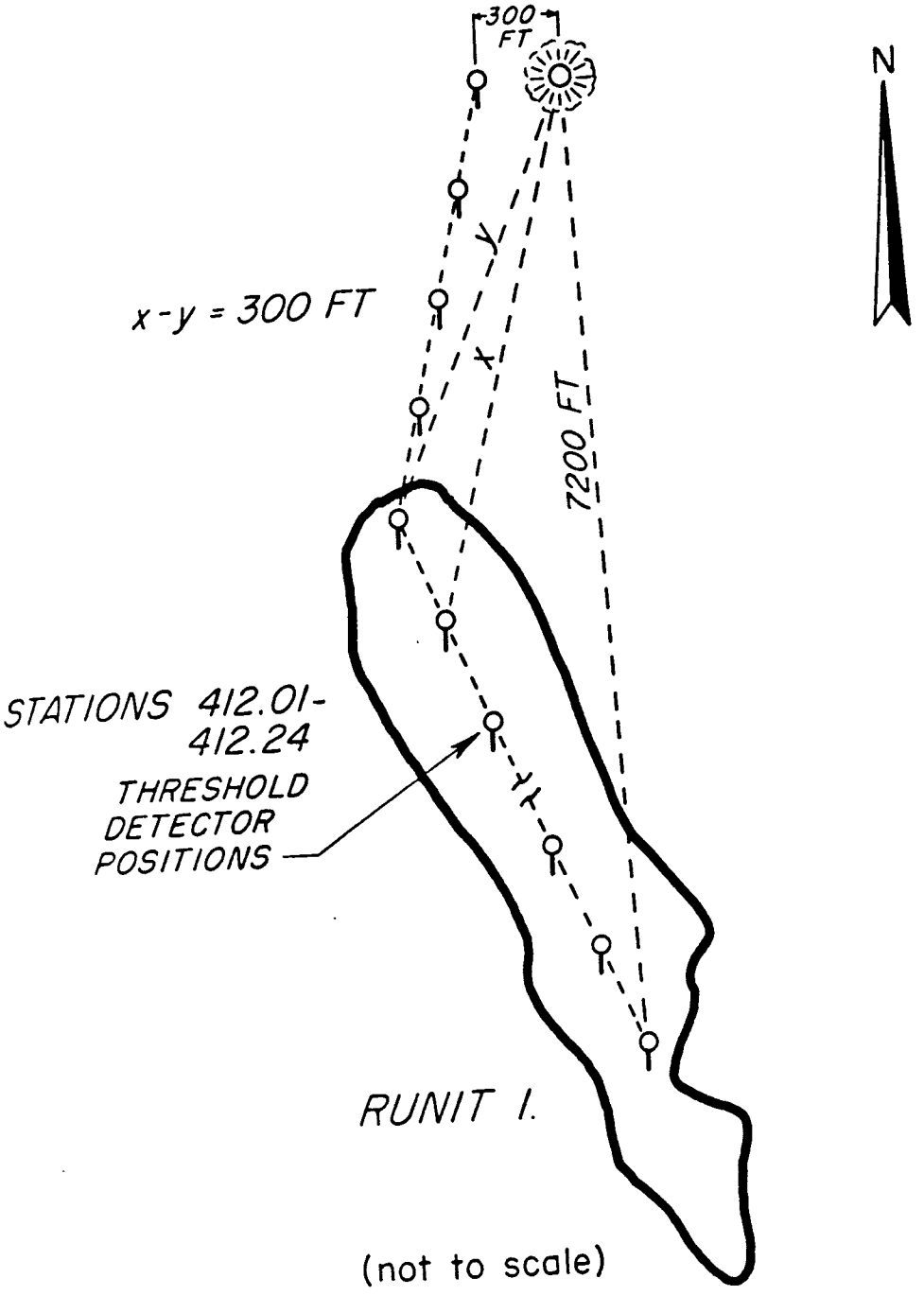


Fig. 4.1.2
King Shot Slow Neutron Observation

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PROGRAM 4

NEUTRON MEASUREMENTS

Project No: 4.2

Project Title: High Energy Neutron Observations.

Test Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. Clyde L. Cowan
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2844
7-4000

Contracting Agency: Group J-12
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	2	M-35	K/1

Support Required:

Object of the Experiment:

We have seen in the discussion of Project 4.1 the importance of obtaining as much information as possible regarding the distribution of neutron intensity with respect to distance and energy. This project is designed to extend the measurement started in Project 4.1, by documenting the flux of neutrons exhibiting energies considerably higher than .25 EV.

Method and Procedure:

A. The "cross section" of a substance with respect to a particular bombarding particle is a measure of the likelihood that the particle will react with the substance. A high cross section implies a high probability of reaction, and so forth. In general, the magnitude of this cross section is a function of the particle energy and type. As an example, consider the cadmium used in Project 4.1. We mentioned that cadmium absorbed essentially all neutrons having energies from thermal to .25 EV, and was "transparent" to those of energy greater than .25 EV. Cadmium thus has a very high cross section for neutrons in the .025 to .25 EV energy range, and a very low cross section for those of energy greater than 0.25 EV.

A threshold detector is a substance having an essentially zero cross section to particles of energy below a fixed level, and a finite cross section to particles of energy greater than that level. The fixed level is the threshold energy for that substance. Sulphur, iodine, and zirconium are examples of threshold detectors - each having quite different reaction characteristics and threshold energies. We shall discuss each of these in turn, with the view of indicating its usefulness to this project.

Sulphur (S^{32}) has a threshold energy of effectively 3 MEV. The reaction which takes place when sulphur is bombarded with neutrons of energy ≥ 3 MEV leads to the creation of a radioactive isotope of phosphorus (P^{32}). This active isotope in turn decays (with a 14.3 day half life)back to S^{32} by emitting 1.8 MEV beta rays. Thus, the specific beta activity of a sulphur sample measures the total number of neutrons with energies not less than 3 MEV that passed through the sample.

Iodine (I^{127}) exhibits a threshold energy of approximately 9.5 MEV. When it is bombarded with neutrons of energy greater than the threshold value, another isotope of iodine (I^{126}) is formed. The latter is radioactive, and decays (with a 13-day half life) to a stable isotope of Xenon (Xe^{126}) by emitting a 1.1 MEV beta particle

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and a 0.5 MEV gamma ray. Hence the specific activity (both gamma and beta) of the iodine sample is a measure of the total number of neutrons having energy in excess of 9.5 MEV which passed through the sample.

Zirconium (Zr^{90}) has a threshold energy of effectively 12.5 MEV. This reaction, upon bombardment with neutrons of sufficiently high energy, produces atoms of Zr^{89} - a radioactive isotope of zirconium. This in turn decays (with a 78-hour half life) to a stable isotope of yttrium (Y^{89}) by emission of a 1 MEV gamma ray. The specific gamma activity of the zirconium sample is then a measure of the total number of neutrons (of energy >12.5 MEV) which passed through the sample.

An experimental procedure is thus indicated. Let us place samples of each of the above elements at some fixed distance from the bomb. Post-shot analysis of these samples will then supply three points on the curve of E (neutron energy) versus N(E), the total number of neutrons with energy at least as great as E. This curve is, of course, associated with the above mentioned distance. A family of such curves can be obtained by placing sets of samples at various distances. From such a family other curves can be derived - for instance those relating N(E) to distance, a different curve being drawn for each value of E.

B. For MIKE shot, sulphur, zirconium and iodine samples will be placed at the same positions mentioned under Project 4.1 (MIKE shot). In addition, a few zirconium samples may be placed on Elugelab - in line with the collimator holes mentioned under Project 2.3 - out to a distance from zero of approximately 800 yards. The placement of the latter is dependent upon space availability, as the collimation may be sufficiently "tight" to forbid extra material in the line of sight. The sample recovery and shipment (to the Los Alamos laboratories) procedures will be identical to those outlined for Project 4.1. For KING shot, sulphur samples will be placed at the same positions as the tantalum samples mentioned under Project 4.1 (KING shot).

Remarks:

1. The above discussion of sulphur, iodine and zirconium as threshold detectors has been over-simplified in the interests of brevity. In actuality, the specific activity of a sample may not be completely neutron-induced. Both iodine and zirconium also react to gamma rays in a very similar fashion. Hence the experimenter must separate the neutron-induced and the gamma-induced activities. One method of doing this is to duplicate such samples in the experimental set-up, one of each pair being surrounded by lead - lead having a very high cross

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section for gamma rays and a very low cross section for neutrons. The difference in specific activity of two such samples is then the activity induced by the gamma rays, etc. The reader is referred to the Project Officer for details of this and other difficulties.

2. In addition to the above, it may be possible to obtain more points on the curve with the following threshold detectors - lack of documentation for which forces their use to be classified as feasibility tests:

(a) Neptunium (Np^{237}) with a .5 MEV threshold for fission.

(b) Uranium (U^{238}) with a 1 MEV threshold for fission.

(c) Arsenic with two thresholds, one at 10.5 MEV and one in the thermal range, the results of which can be separated with special analysis techniques.

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PROGRAM 4

NEUTRON MEASUREMENTS

Project No: 4.3

Project Title: Neutron Spectrum - Nuclear Emulsions.

Joint Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Dr. Clyde L. Cowan
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2844
7-4000

Conducting Agency: Group J-12
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	1	M-35	K/1

Support Required:

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Object of the Experiment:

The discussion of Project 4.1 pointed out the desirability of obtaining the total neutron spectrum (numbers of neutrons at every energy level) versus distance. However, the techniques of Projects 4.1 and 4.2 do not allow a determination of the entire spectrum. This project makes use of an experimental technique which, if successful, is capable of much more extensive documentation of the neutron energies existent at a given distance.

Method and Procedure:

A. Certain elements, upon neutron bombardment, undergo an (n,p) reaction. That is, the absorption of a neutron is accompanied by the ejection of a proton, the energy of which is proportional to the energy of the absorbed neutron. If the proton is allowed to travel through a photographic emulsion, it will produce a "track" of ionized particles and hence a track of "exposure". Upon development, the photographic negative will exhibit a dark line, the length of which is proportional to the proton energy. As a result, laboratory calibration of this technique allows the measurement of the resulting line in the negative to be interpretable as the energy of the incident proton.

This technique has a number of serious disadvantages, however. First, the film must be adequately shielded from both neutrons and gamma rays, as both are capable of producing "exposure" of the emulsion. Secondly, the proton source is also sensitive to gamma rays, and must be shielded from them if the experimental record is to be useful as a neutron indicator.

These difficulties are met, at least partially, by heavy shielding for the assembly (proton source and photographic plate) and strong collimation for the signal - with lead in the collimation line to keep the gamma rays away from the proton source. The necessary collimation creates more disadvantages, however. The experiment cannot be conducted on air drops because of the uncertainty in burst position, and the "good geometry" results are not applicable to the needs of those interested in the biomedical effects of neutrons. After all, it is most unlikely that the soldier in the field would be exposed to an atomic bomb in a collimated geometry.

B. For MIKE shot, one nuclear emulsion camera will be operated at 1300 yards from bomb zero. This is primarily a feasibility test for the equipment, as the gamma-ray level at such a distance from the gadget will be sufficiently high to make film-fogging marginal.

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[redacted]

The camera cannot be moved further away, however, as the neutron signal strength at that distance is marginal (for obtaining a usable experimental record) on the low side.

Remarks:

At first glance, it might appear that the disadvantages associated with this experiment far outweigh the advantages to be gained from its success. This is not the case, however, as the spectrum information it may obtain would be of great theoretical value. Also, it can be simply and cheaply done with reclaimed GREENHOUSE equipment that has been kept in storage on Parry Island.

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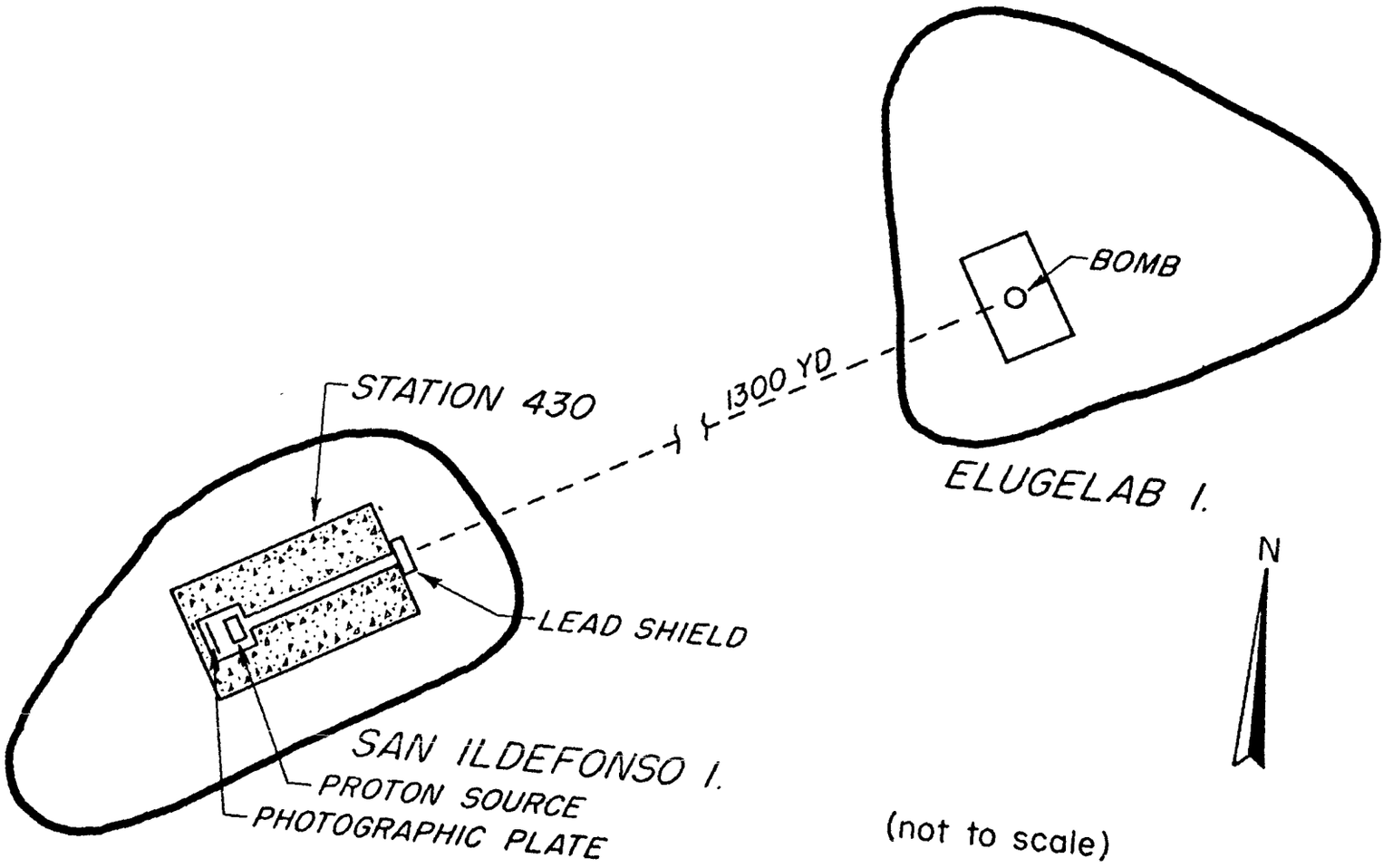


Fig. 4.3.1
Mike Shot Neutron Spectrum - Nuclear Emulsions

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PROGRAM 4

NEUTRON MEASUREMENTS

Project No: 4.4

Project Title: Neutron Intensity as a Function of Time.

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. Clyde L. Cowan
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2844
7-4000

Conducting Agency: Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-35	K/1
Enlisted			
Civilian			

Support Required:

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Object of the Experiment:

The neutron detection methods outlined in Projects 4.1 and 4.2 are essentially time integrating, and offer no information as to the time distribution of the original flood of neutrons. This project is designed to gain information as to the total number of arriving neutrons versus time at given fixed distances from bomb zero. The device which accomplishes this purpose is called a "fission-catcher camera" and its method of operation is discussed below.

Method and Procedure:

A. The fission-catcher camera consists essentially of a thin foil of fissionable material, behind which a cellophane strip is moved at a known rate. If the fissionable material is subjected to bombardment by neutrons of the proper energy, some of its atoms will undergo fission, and the by-products of these fissions will be thrown out as fission fragments. The fragments will be picked up by the moving cellophane strip, and their position on the strip will be a measure of when they were created. Since many fission by-products are radioactive, their presence on the strip can be detected by laboratory "counting" techniques. Hence by measuring the activity of the cellophane strip as a function of distance along the strip, one can, by using the known strip velocity and starting time, deduce the period of time over which fission producing neutrons arrived at the camera.

B. For MIKE shot, three fission catcher cameras will be located on San Ildefonso island approximately 1200 yards from zero. Foils of both uranium 235 and uranium 238 will be used as the fissionable material, the U^{235} being used both with and without cadmium shielding.* U^{235} has a thermal ($\sim$.025 EV) energy threshold for the fission reaction, and U^{238} has a similar threshold at 1 MEV.** Analysis of these cellophane "films" should then supply us with the following information:

(a) The time distribution, at 1200 yards from zero, of the neutrons in the energy range from 0.25EV to 1 MEV.

(b) The time distribution, at 1200 yards from zero, of those neutrons having energies in excess of 0.25EV.

* See the discussion of Project 4.1

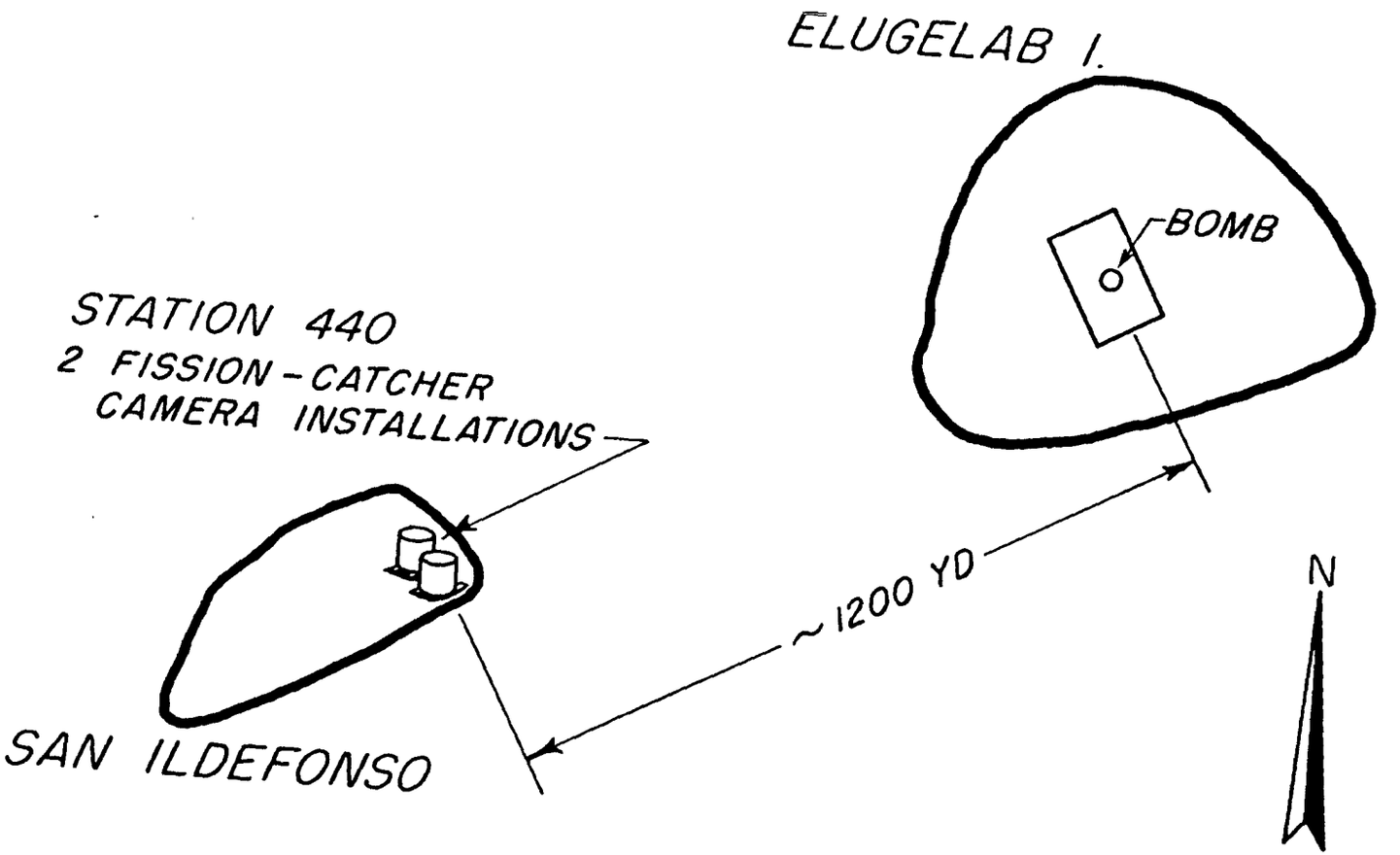
** See the discussion of Project 4.2

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(c) The time distribution, at 1200 yards from zero, of those neutrons having energies in excess of 1 MEV.

In each case, these measurements will start at approximately 1 millisecond after zero and continue for 30 seconds.

For KING shot, an identical installation will be made on the north end of Runit island.



(not to scale)

Fig. 4.4.1

Mike Shot Neutron Intensity as a Function of Time

Mike Shot Neutron Intensity as a Function of Time

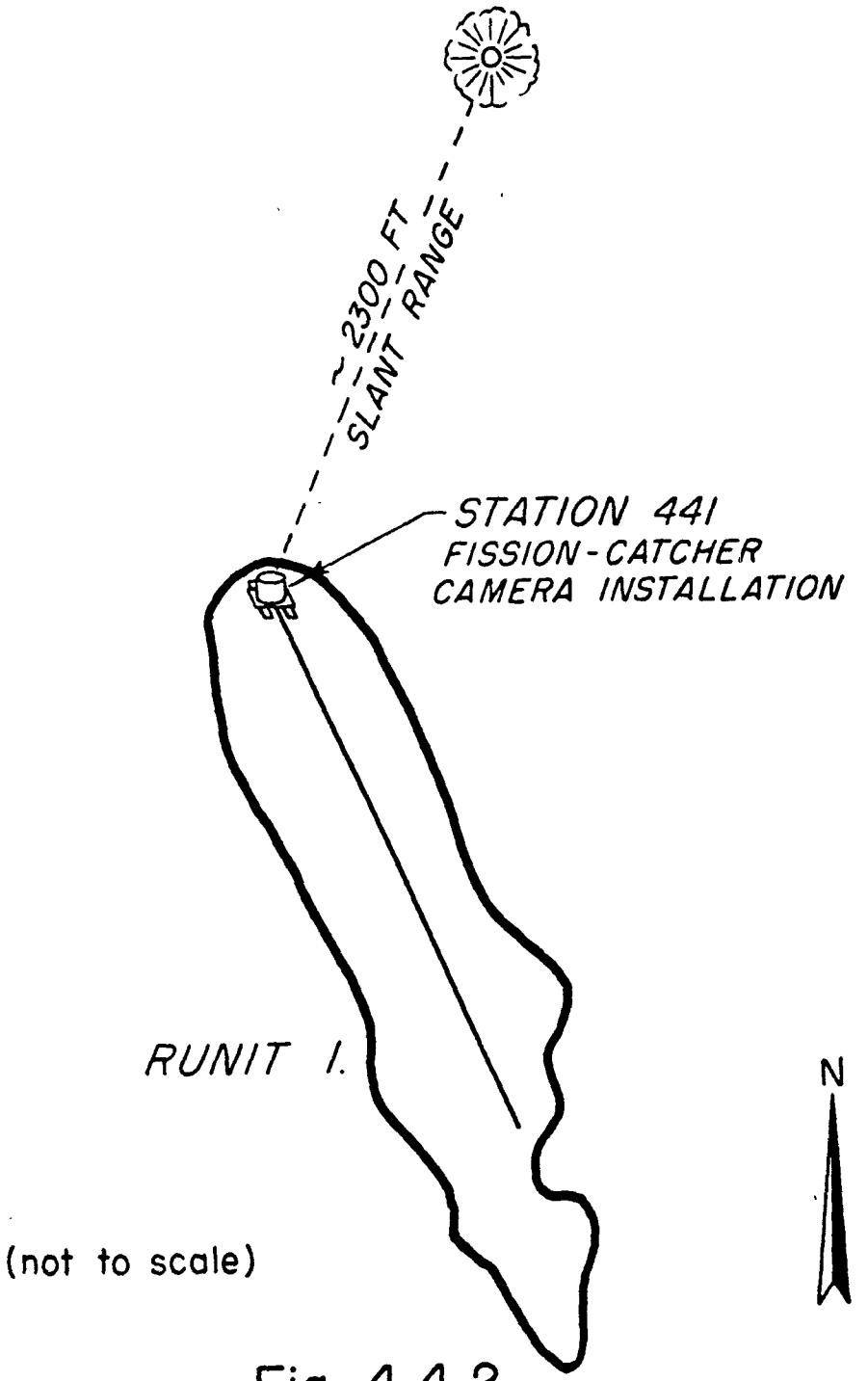


Fig. 4.4.2
King Shot Neutron Intensity as a Function of Time

PROGRAM 5

GAMMA RAY MEASUREMENTS

Project No: 5.1 Project Title: Total Dose.

Test Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Mr. Ellery Storm
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-3744

Conducting Agency: Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	4	M-21	K-10

Support Required: Courier facilities for returning film to the Los Alamos processing laboratories.

///

Object of the Experiment:

In the field of atomic weapons effects, knowledge of the gamma radiation dose resulting from a bomb detonation - as a function of distance, energy release, time and weapon type (i.e., fission or thermonuclear) - is of obvious importance. Since a non-negligible fraction of the total energy involved is released as gamma radiation of various energy levels, we have a serious personnel hazard assured for some distance from bomb zero. The more knowledge we possess about this hazard, the better we can plan for defense against (and tactical use of) atomic weapons. As a particular example, consider the problem of telling the foot soldier how to prepare a fox hole in such a way that he will most efficiently utilize the time available to him in obtaining protective shielding from gamma rays. As another, we have the problem of where to plan the concentration of disaster relief team efforts for civil defense. This experimental project is part of a continuing program, the purpose of which is to obtain as much documentation as possible of the gamma radiation fields established by exploding atomic weapons. In particular it is designed to supply information as to the total gamma dose received by points located at various distances from bomb zero.

Method and Procedure:

A. It is common knowledge that photographic (silver halide) emulsions react to light in such a way that subsequent chemical reduction (development) of the emulsion causes opaque deposits of metallic silver to be produced - the relative opacity (density of silver deposit) being proportional to the original light intensity. Such a phenomenon might supply an experimental method for determining the strength of a light source, by carefully calibrating the emulsion, development technique, and negative density measurements - and by using known attenuators for very strong sources.

Consider, however, the fact that visible light represents but one small portion of the electromagnetic radiation spectrum. Other portions of that spectrum; for instance, X-rays and their more energetic brothers gamma rays, are capable of producing the same reaction in the silver halide suspension. Hence we have modern X-ray photography - and the film badge dosimeter.

The film badge dosimeter consists of a small packet containing several strips of photographic film - the packet being made light-tight to insure that "exposure" is due only to penetrating radiation. Quality control in the film manufacturing, and laboratory calibration of samples from each film batch used, insure that the field exposure of a packet

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...l be interpretable directly in terms of roentgens of gamma ray dose ...eived.

After the badge has been exposed, the analysis technique consists ...f first developing the film under carefully controlled conditions ...that is, conditions precisely like those with which the film was cali...rated), then measuring the opacity of the negative with a precision ...ensitometer. The densitometer measurement will be interpreted as so ...ny roentgens by the above mentioned laboratory calibration.

Exposure of the film, of course, tells us only that one or more ...amma photons were there. It cannot, in itself, tell us when. Hence ...e film is a time integrating device, and measures only the total ...amma dose received by it from the time it was made until the time it ...as developed. This fact indicates the absolute necessity of adequate...y shielding unexposed packets from extraneous radiation sources (for instance, fallout).

Photographic film, like all other gamma ray detectors, is somewhat energy sensitive - that is, the degree of "exposure" due to gamma ray passage is somewhat dependent upon the energy of the gamma. This effect, however, is essentially a calibration problem, and need not be considered herein. For such details the reader is referred to the Project Officer. For all practical purposes, one can give the final result of this measurement as so many roentgens of gamma - of energy sufficiently great to penetrate the protective covering of the packet.

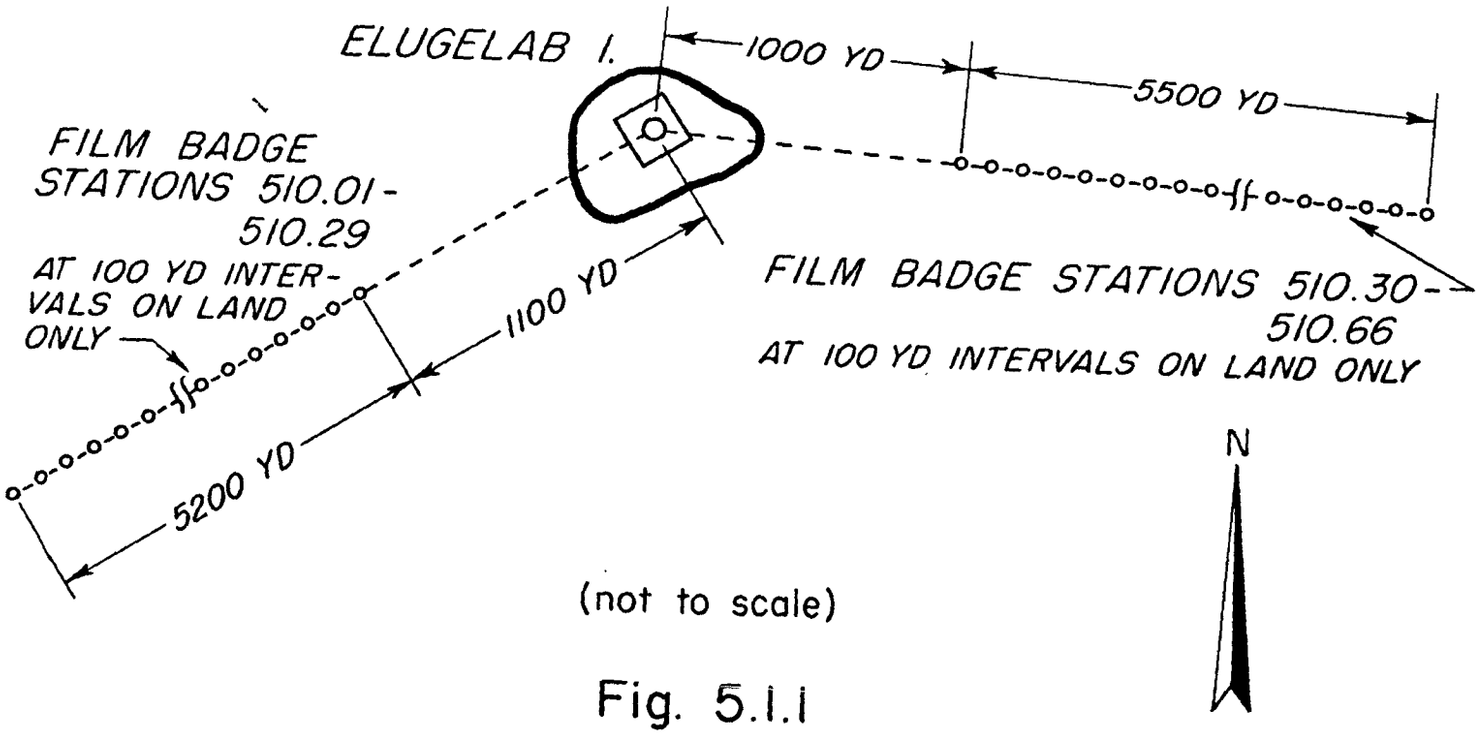
The inclusion of several strips of film in each packet is an economy measure. The measurement of a fifty roentgen dose is more efficiently accomplished on a film strip that is strongly exposed by one hundred roentgens than it is on one which requires one thousand roentgens for strong exposure - the contrast between the correct densitometer reading and one slightly incorrect being much easier to detect. Hence the inclusion of only one film strip per packet would require several different packet models for the various distances from bomb zero (likely gamma exposure ranges) of interest. Packet standardization, in such a way that each packet is capable of use at any measurement station, effects an obvious logistical simplification.

B. For MIKE shot, two measurement lines will be established - one from Elugelab to the far end of Bogallua, and one from Elugelab to the far end of Engebi. The packet positions will be on land only, and will be spaced at one hundred yard intervals insofar as possible. Three film badges will be placed at each position, the first of which remains openly exposed to radiation until recovery. The second and third badges will be openly exposed initially, but will later drop into prepared shielded positions - the second dropping 0.2 seconds after the explo-

sion, and the third dropping 60 seconds later. In this fashion, a crude time resolution of the total dose will be obtained - providing the shield corrections can be adequately made. In particular, the spreading of contamination by a "base surge" or "dust skirt" may be documented in this fashion.

For KING shot, a line of film badge stations will be placed down the middle of Runit - spaced at approximately one hundred yard intervals. Each station will consist of a post to which one or more film badges is attached. All badges will be openly exposed until recovery.

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(not to scale)

Fig. 5.1.1

Mike Shot Total Dose

5.1.5

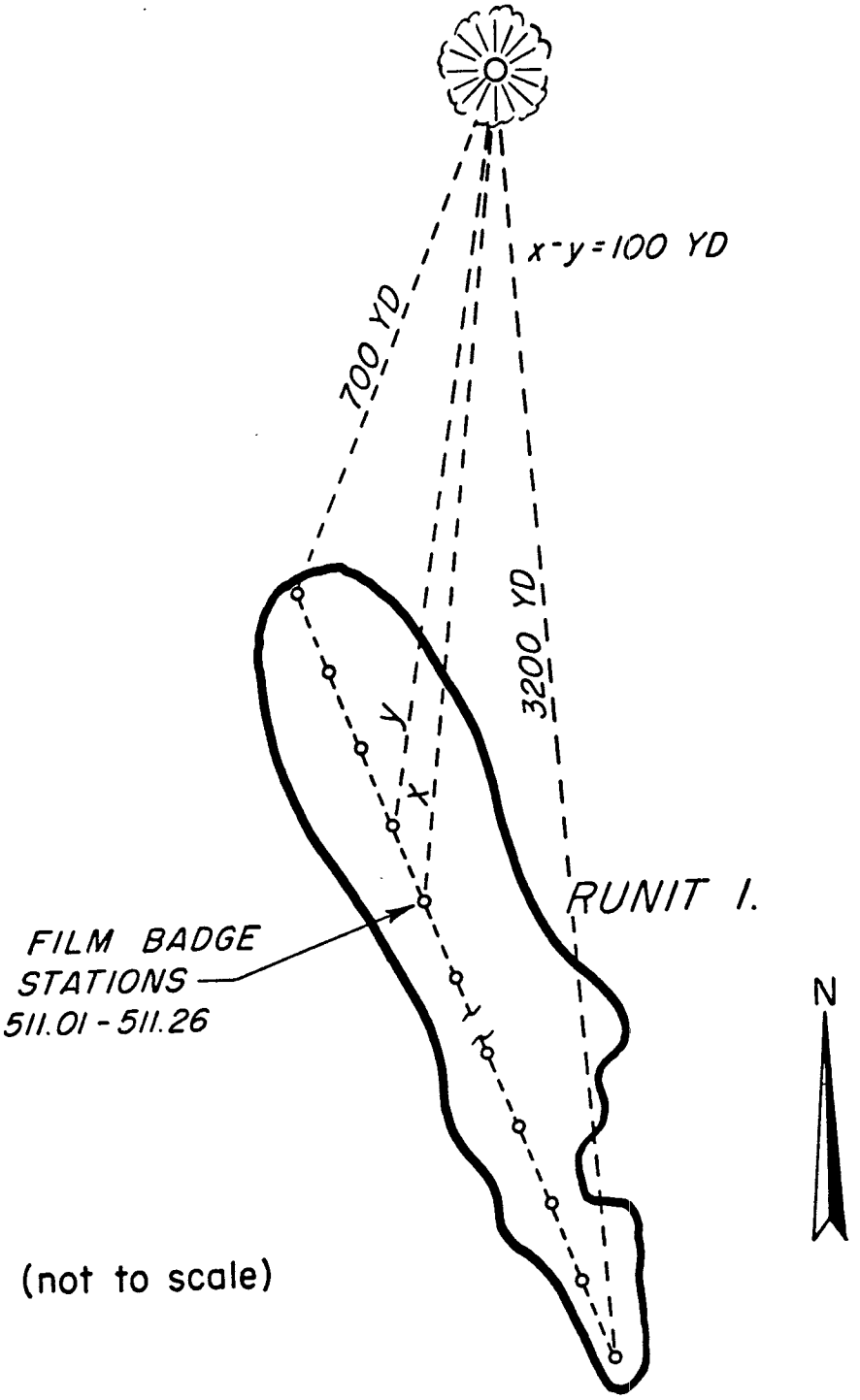


Fig. 5.1.2
King Shot Total Dose

PROGRAM 5

GAMMA RAY MEASUREMENTS

Project No: 5.2 Project Title: Gamma Intensity as a Function of Time.

Unit Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. John S. Malik
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-4106

Conducting Agency: Group J-13
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-45	K/15
Enlisted			
Civilian	3	M-45	K/15

Support Required:

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Object of the Experiment:

Consistent with the idea of eventually having complete documentation of the "field variables" associated with an atomic weapon detonation, this project is intended to measure the time dependence of gamma ray intensity (at certain fixed distances) from shortly after zero time to plus thirty seconds.

The gamma rays which are emanated from an exploding atomic bomb fall into two distinct classifications - "prompt" and "delayed". The prompt gamma rays are those created during the reaction time of the bomb - this time being dependent upon the bomb model, but usually being some fraction of a microsecond.

The delayed gamma rays come from two quite distinct sources, each source contributing approximately one-half of the total:

(A) Those liberated by the decay of the active fission fragments, their time dependence depending upon the fate of the fragments - when they are swept up by the rising fireball, or where they are deposited on the ground.

(b) Those arising from (n,γ) reactions in the soil and in the air around the bomb.

In any above-surface burst the vast majority of fission fragments will be carried up by the fireball; hence the greater portion of delayed gamma radiation occurs during the first few seconds after the explosion, although weak radiation may continue for a long time because of a few active fragments being deposited in the surrounding soil.

The time dependence of the prompt gammas is documented by the "Alpha" experiment, and will not be considered here. This experiment is designed to start at 0.2 microsecond (μs) for MIKE shot (1 millisecond (ms) for KING shot) and extend for approximately 30 seconds - thus measuring the time dependence of the major portion of the delayed gammas.

Method and Procedure:

A. The detection method used herein is essentially the same as that used in Project 2.1a. A "phosphor" (substance which fluoresces under gamma ray bombardment - to produce a light signal, the intensity of which is proportional to the intensity of the incident gamma radiation) observes the bomb, and is itself observed by a photocell (current

generator - the magnitude of generated current being proportional to the intensity of the light signal it "sees"). The current signal from the photocell is converted to a voltage signal in a so-called "logarithmic attenuator" and applied to the deflection plates of an oscilloscope. The timing equipment is included in the horizontal deflection plate circuit of the scope in such a way that a given horizontal deflection of the electron beam is uniquely associated with a given elapsed time from zero. Hence the scope trace is a gamma intensity versus time record, the vertical scale of which is not gamma intensity itself but a known function of the gamma intensity - the known function being supplied by the experimentally determined characteristics of the logarithmic attenuator.

The logarithmic attenuator is an electronic device which, upon receipt of a signal of magnitude M, passes on a signal whose magnitude is proportional to log M. Hence it passes on small signals with little or no attenuation, whereas it attenuates large signals a great deal. Such a device is necessary in this experiment because of the tremendous range of gamma intensities involved. Since a given oscilloscope has a limited intensity range, direct recording of all gamma intensities involved herein would require a prohibitive number of scopes. The use of the above mentioned attenuator allows the use of only a few scopes, each covering several decades (powers of ten) of gamma intensity.

B. For MIKE shot, gamma intensity versus time measurements from 1 ms to 30 seconds (covering 6 decades of intensity) will be made on four islands - Cochiti, San Ildefonso, Bogombogo, and Ruchi. Hence four points will be obtained on the gamma intensity versus distance curves - each curve being associated with a given elapsed time after zero. In addition, on Ruchi island, measurements will be taken from 0.2 to 1000 μs, covering approximately 8 decades of intensity.

For KING shot, three measurement assemblies will be placed on Runit - at varying distances from bomb zero. The time coverage here will be from 1 ms to 30 seconds, and approximately 6 decades of signal will be recorded.

Remarks:

1. The retentive face of a cathode ray tube is caused to fluoresce by incident ionizing radiation - just as it is by the electron beam generated within the tube. Such a phenomenon can cause loss of experimental measurement, if it occurs during the time that a desired trace is being generated and photographed. As a result, recording oscilloscopes near the exploding bomb must be shielded from ionizing ra-

diation rather thoroughly.

As a result of this, the usual gamma-versus-time station consists of a hole in the ground - some 18 to 20 feet deep - at the bottom of which the recording equipment is placed. The hole is filled with water to obtain extra shielding, and the detector is placed above the surface of the ground. Hence the only outward manifestation of the stations existence is a bell shaped aluminum object (the detector cover) sitting on a steel plate (the hole cover). For this project, all stations not on Ruchi island will be as described above.

The Ruchi station will consist of a small blockhouse, in which a number of detectors for nearby recording equipment will be placed. This more complicated installation is made necessary by the greater time resolution (and attendant complexity of instrumentation) required of the Ruchi measurements.

2. The Ruchi blockhouse will be supplied with a timing signal by EG&G, to actuate the recorders. The self-contained units will be actuated by the "blue boxes".

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(not to scale)

Fig. 5.2.1
Mike Shot Gamma Intensity as a Function of Time

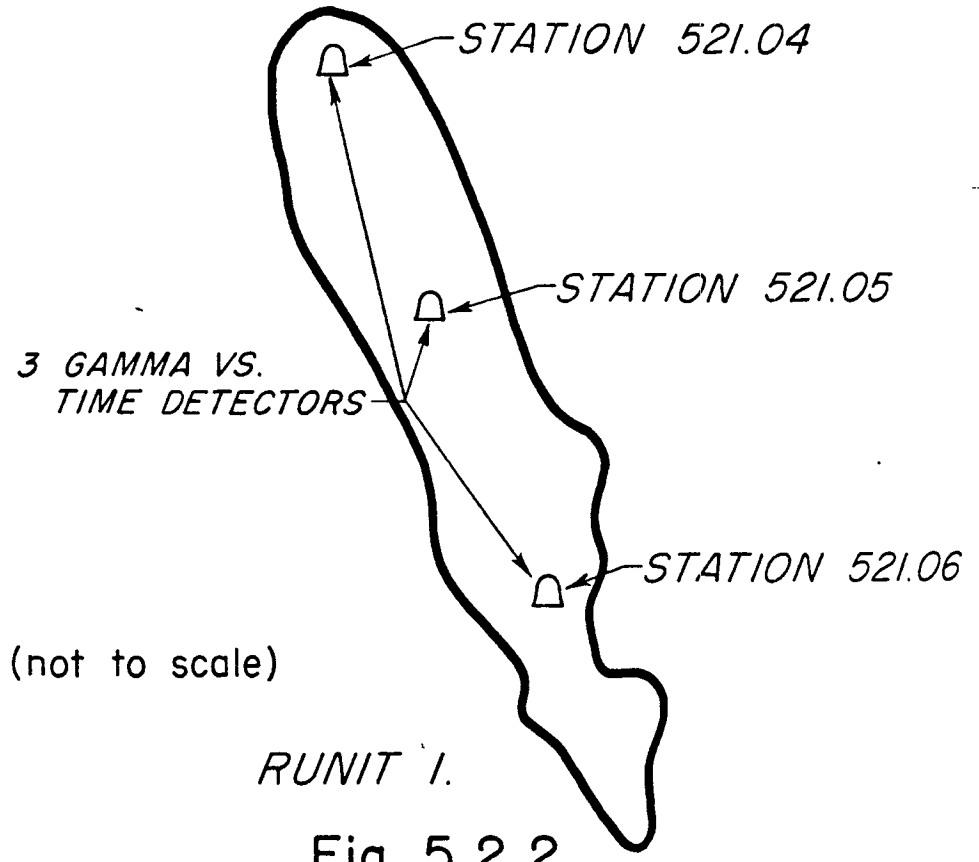


Fig. 5.2.2
King Shot Gamma Intensity as a Function of Time

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PROGRAM 5

GAMMA RAY MEASUREMENTS

Project No: 5.3

Project Title: Fall-Out Gamma Intensity.

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Dr. John S. Malik
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-4106

Conducting Agency: Group J-13
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-45	K+15
Enlisted			
Civilian	1	M-45	K+15

Support Required:

[redacted]

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[redacted]

Object of the Experiment:

The "fall-out" of radioactive particles from an atomic cloud presents a problem, the solution of which is potentially important to every living thing on our planet. Because of this phenomenon, a bomb burst over Nevada may require the evacuation of areas in another state - or a bomb burst over the enemy may endanger friendly troops many miles away. Of even more immediate interest to us at this time, MIKE shot may constitute a hazard to Runit island, Kwajalein, or perhaps even Oahu.

The winds of our atmosphere are primarily responsible for this ability of an atomic bomb to threaten at great distances. As a result of this fact, every experimental detonation made by this country to date has had its firing scheduled by the vagaries of nature - to minimize the possibility of hazardous fall-out. In time of war, however, (and particularly where the tactical deployment of atomic weapons is concerned) it may be necessary to forego a minimizing procedure in favor of a calculated risk - for defensive planning as well as offensive. Hence a relatively complete understanding (or a proven sufficiently accurate approximation thereto) of the fall-out mechanism is essential. A calculated risk is unworthy of the name if the risk cannot be calculated.

To better understand the above statements as to the importance of understanding fall-out, and to gain a feeling for how documentation of the phenomenon can be made more feasible, let us briefly consider a qualitative picture of what fall-out is and does.

As we mentioned in the discussion of Project 5.2, a vast majority of the radioactive fission particles are swept up to altitude by vertical winds - the winds being created by the rising fireball. These particles are of many types, and cover a wide range of sizes (for instance from a small fraction of a micron (μ)* to 1 millimeter (mm) in radius). They produce ionizing radiation of half-lives** ranging from a fraction of a second to thousands of years. The maximum altitude to which a particular particle is carried is a function of its size and the average vertical wind velocity to which it is subjected -

* 1 micron = 10^{-6} meters

** The half-life of a radioactive source is the amount of time necessary for it to decay to one-half its original strength.

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and hence of the yield of the weapon. After this maximum altitude is reached, the path of the particle is affected by the downward pull of gravity and whatever forces the atmospheric air motions (winds - both vertical and horizontal) may impose on it.* Hence its path in space will vary from nearly a simple parabola to extremely tortuous curves that defy analytical representation.

Regardless of what such a path may be, however, common sense tells us that it will intersect the ground sooner or later - sooner for large particles and later for small particles. After reaching the ground, a particular particle constitutes a personnel hazard - the magnitude of the hazard depending upon:

(a) The type of decay radiation produced by the particle - gamma, beta, or alpha, for instance.

(b) The energy of the decay radiation, which determines its effective range.

(c) The time after zero, which determines the source strength.

The ultimate theoretical goal in this field is the development of an adequate theory for prognostication of the fall-out-induced dose rate at any point. This can be naturally separated into two distinct problems, as follows:

(a) The problem of deducing particulate fall-out for a given point, and

(b) The problem of deducing the dose rate that will be experienced due to exposure to the above mentioned particles.

The second of these is adequately solved by using an empirically determined average decay rate for fission fragments - namely, that the dose rate is proportional to the inverse 6/5 power of time.

* Unless the particle is sufficiently small to undergo "Brownian movement". In this case, the dominating factor in its motion is bombardment by molecules of air, and its path in space will be dictated by chance. For the sake of simplicity, we shall ignore these particles (radius < approx. $1/2\,\mu$), although it is by no means clear that such a simplification is justifiable from the viewpoint of contributing a negligible fraction of fall-out-induced radiation hazard.

The existence of the second, however, implies that we must know when the particle arrived at a point - the mere fact that it did arrive is not enough. A simple theory explaining the latter phenomena has been evolved, but it requires extensive corroboration and calibration before it can be used with confidence. Prior to BUSTER/JANGLE, the necessary experimental data was not available - since all fall-out measurements were time-integrating (for instance, film badges). This project is intended to further the documentation (started in conjunction with Nevada tests) of fall-out intensity versus time at various fixed points.

Method and Procedure:

A. The instantaneous dose rate at a given point will be measured with an ionization chamber - a device which produces a current signal upon the passage of ionizing radiation. A permanent record is obtained of this instantaneous measurement by using the current signal to drive a pen on a Esterline-Angus (or its equivalent) recorder. Measurement of the pen trace thus obtained will furnish radiation intensity versus time data - the lateral displacement of the pen being proportional to radiation intensity, and the longitudinal position of a point on the paper being a measure of time after zero.

B. Recording devices, of the above mentioned type, will be installed on Bogallua, Rigili, Parry, Biijiri, Engebi, Runit, and Bogon islands. The records from Engebi and Bogon will be telemetered to Parry, in order that the initial recovery teams (on Parry) may know the personnel hazard existent in the northern part of the atoll at that time. All units will be self-contained, and actuated by time clocks.

In addition, it is planned to install such monitoring devices on some ten other atolls in that portion of the Pacific.

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PROGRAM 5

GAMMA RAY MEASUREMENTS

Project No: 5.4a

Project Title: Fall-Out Distribution and Particle Size.

Test Participation: MIKE

Sponsor: DOD (USN - BUSHIPS)

Project Officer:

Name: Lcdr. W. B. Heidt, Jr.
Address: c/o Code 348
Bureau of Ships
Department of the Navy
Washington 25, D. C.
Phone: Liberty 5-6700
EXT. 6-2422

Conducting Agency: U.S. Naval Radiological Defense Laboratory

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer	2	M-30	M/15
Enlisted	8	M-30	M/15
Civilian	2	M-30	M/15

Support Required:

(1) Boats to place rafts within the lagoon and ships to transport men and equipment to selected islands outside the atoll.

(2) Manpower to operate stations on board ship and on islands.

* Plus 2 additional civilians from M-60 to M/15.

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Object of the Experiment:

In order to better predict fall-out patterns and probable external and internal hazards to personnel from radioactive fall-out, previous atomic weapons tests have mounted experiments to measure fall-out. As a result, after the SANDSTONE tests a secondary fall-out was reported at Kwajalein (400 miles distant) on YOKE plus 1 day. This fall-out occurred as radioactive rain which fell intermittently during a period of about 10 hours. The maximum activity reported was 6 mr/hr on exposed cloth and tent sides and 10 mr/hr in dried puddles. At Operation GREENHOUSE following DOG shot, a fall-out occurred over the southern half of Eniwetok Atoll. The fall-out on Eniwetok Island started approximately three hours after the shot and continued to build up for a few hours, reaching a peak in excess of 40 mr/hr by mid-afternoon. No secondary fall-out was observed through D plus 6 days. Within a few hours after EASY shot, a fall-out occurred which was restricted to the northern islands of the atoll, near Engebi. A small secondary fall-out occurred on E plus 1 day which was observed only on Aniyaanii, Parry and Eniwetok.

If the yield on MIKE shot approaches that which has been predicted, the cloud can be expected to rise considerably higher than that from any previous test. The gathering of fall-out data from this shot is therefore a logical extension of previous fall-out documentation. The data collected will have direct application in the appraisal of potential health hazards to personnel from external and internal exposure to the fall-out products. It will also furnish additional information for predicting fall-out patterns from other atomic detonations.

This experiment has been designed to accomplish the following objectives:

A. To extend the measurement of fall-out distribution and magnitude following MIKE shot to distances greater than those being documented by Project 5.3. For the most part, this will involve instrumentation of the sea areas around Eniwetok Atoll.

B. To determine, at a limited number of close stations, the rate of arrival of inert liquid or solid materials and associated radioactive materials.

C. To obtain data on size distribution and chemical nature of the active fall-out particles.

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D. To correlate the fall-out pattern obtained with that predicted from a knowledge of meteorological conditions and atomic cloud behavior.

E. To calculate fall-out-induced radiation intensities (versus time) and total dose.

Method and Procedure:

The instrumentation to be utilized in securing the necessary data will include the following type of collecting devices:

Type A — An integrating collector for both liquid and solid fall-out, comprising a collecting area funneling into a flask. The flask is so designed that it can be removed from the collector, sealed and shipped.

Type B — A liquid rate collector consisting of a modified recording type rain-gage. There will be two models of this instrument, one for recording over a period of one week and one for recording over a period of six hours.

Type C — A differential fall-out collector which separates the liquid fall-out with respect to time of arrival at the station.

Type D — A differential fall-out collector which separates the solid fall-out with respect to time of arrival at the station.

Type E — Greased plates which will be replaced each 24 hours for a period of approximately one week after shot time.

The six-hour Type B collectors and Type D collectors will either be started manually or with blue boxes, depending upon their proximity to the weapon.

The land-based station array within the Atoll will consist of the following:

Land Station	Collecting Devices				
	Type A	Type B	Type C	Type D	Type E
Bogallua	1	1	1	1	
Engebi	1	1	1	1	
Yeiri	1	1	1	1	
Piiraai	1	1	1	1	
Runit	1	1	1	1	
Aniyaanii	1	1	1	1	
Parry	1	1	1	1	1
Eniwetok	1	1	1	1	1

It is currently planned that Type D and E collectors will be employed on certain islands outside the atoll. The exact islands to be used will be determined at a later date. Station installation at a selected island outside Eniwetok Atoll can be accomplished by a team of no more than two men - in a maximum of 24 hours. Subsequent operation of the station might be accomplished by personnel permanently assigned to that area - since it would require only 5 man-minutes per day during the period of interest.

It is also planned to use a number of anchored rafts as instrument stations within the lagoon. These raft stations will be assembled on land and towed to anchorage location.

Stations equipped with Type D and E collectors will be established aboard at least one vessel of each task force unit. This equipment can be delivered to the ship well in advance of proposed operations, and, where Project 5.4a personnel are not present, simple operating instructions will be issued to the ship's force.

PROGRAM 5

GAMMA RAY MEASUREMENTS

Type I

Project No: 5.4b

Project Title: Close-In Particulate Cloud and Fall-Out Studies.

Joint Participation: MIKE - KING

Sponsor: DOD (USA)

Project Officer:

Name: Mr. Elmer H. Engquist
Address: Chemical and Radiological Laboratories
Army Chemical Center, Maryland

Phone: Edgewood, Md. 1000
EXTENSIONS 4107, 7267

Conducting Agency: The Chemical and Radiological Laboratories of the U.S. Army Chemical Corps

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	2	M-25	K+7
Enlisted	4	M-30	K+7
Civilian	3	M-25	K+7

Support Required:

(1) The use of a liaison type aircraft or helicopter for the aerical survey.

(2) Rad-Safety monitors for survey recovery operations.

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Object of the Experiment:

At Operations SANDSTONE, GREENHOUSE and BUSTER/JANGLE, the Chemical Corps secured a great deal of data on the distribution of particulate matter in atomic explosion induced radioactive clouds. At Operations SANDSTONE and GREENHOUSE much of this data was obtained by using samplers on drone aircraft. It was used in determining the predominant sizes of gross and radioactive particulates, particulate activity per unit volume of the cloud, specific activity of particulate matter, fractionation of radionuclides with particle size, gross weight of fall-out per unit area as a function of distance and airborne activity contours in the area of cloud travel.

The object of this experiment will be to obtain the following specific data from the clouds produced by Operation IVY atomic detonations:

a. Total activity in the particulate material.

b. Rate of fall-out and the fall-out pattern on land areas of Eniwetok atoll.

c. Determination of the airborne concentration of the radioactive particulate matter near ground level over land areas of Eniwetok atoll.

d. Determination of size distribution of gross and radioactive particulate matter.

e. Distribution of activity with particle size.

f. Determination (with radiochemical techniques) of the presence of selected fission products in the particulate matter.

g. Determination of the adequacy of aerial survey systems in assessing the ground contamination situation.

These data will supplement the previous atomic bomb phenomena observations in the determination of the following:

a. The hazard to personnel resulting from residual fall-out and airborne activity.

b. The contamination of areas and structures.

c. The development of decontamination measures.

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Method and Procedure:

The collection of the necessary samples will be accomplished by sampling aircraft for air samples and the Intermittent Fall-Out Sampler and Electrostatic Precipitator for ground samples. These methods and equipment will be discussed in detail below:

Air Sampling - Air sampling aircraft will collect a total sample of gaseous and particulate material from the cloud for the purposes of Project 7.3 and this project. This project will analyze the particulate sample for cloud particle size and distribution. The sampling will be accomplished by F-84G aircraft, each being equipped with a cloud sampler. The latter will be installed in the nose of the aircraft with a probe extending forward of the nose through a gunport. The probe contains a solenoid operated valve and is attached to a flexible plastic bag. Initially the bag will be deflated and the valve closed. Upon entering the cloud following the detonation, and at a given radiation level, the pilot actuates a switch opening the solenoid valve. The probe samples the air isokinetically, to fill the bag within approximately ten seconds. The gas sample is subsequently pumped out through a filter into shipping bottles. Both bag and filter will finally be shipped to the ZI for detailed particulate analysis.

Intermittent Fall-Out Sampler - The intermittent fall-out samplers will be located on various islands of the atoll, and will operate in such a way as to document fall-out as a function of time. These samplers will be designed to the following specifications:

a. Initially water-tight to prevent entry of water.

b. Equipped with a Blue-Box with a time delay relay to start the sampling cycle at H-hour plus 5 to 10 minutes.

c. Total sampling time of six (6) hours.

d. The unit will sample fall-out intermittently, with a time interval between sample collections of fifteen minutes.

e. Battery, or spring-wound motor, operated.

f. Sampling surface readily removable from the equipment to facilitate shipment.

It is planned that one of these Intermittent Fall-Out Samplers will be located on each of the following islands of Eniwetok atoll:

Bogallua	Rojoa
Bogombogo	Aaraanbiru
Ruchi	Piiraai
Bogon	Runit
Engebi	Aniyaanii
Muzin	Japtan
Kirinian	Parry
Bokonaarappu	Eniwetok
Yeiri	Igurin
Aitsu	Giriinien
Rujoru	Rigili
Eberiru	Coral Head
Aomon	Artificial Island
Biijiri	

Duplicate stations will be established at Engebi, Eberiru, Runit, Japtan, Parry, Eniwetok, Giriinien and Rigili.

Electrostatic Precipitator - These will collect samples of airborne particulate material. Each precipitator is self-contained and similar to a portable electrostatic precipitator developed and manufactured by Mine Safety Appliance Company. The collecting surface will be modified to include electron microscope screens for particulate analysis. Such units will be located on Engebi, Eberiru, Biijiri, Runit, Japtan, Parry and Eniwetok.

Aerial Survey - These data will be obtained with survey meters in light aircraft or helicopters,with detailed data being taken with survey meters equipped with recorders. It is planned that these data be taken by a Rad-Safety monitor in each aircraft and made available to this project. Detailed information is required on the altitude, flight path, air speed, estimated ground speed, location relative to the ground, etc., to permit interpretation of the graphical data.

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.1

Project Title: Pressure vs. Time on the Ground.

Unit Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Mr. Harlan E. Lenander
Address: Proving Ground Department
(Code 5230) Sandia Corporation
Sandia Base, Albuquerque, New Mexico

Phone: Albuquerque 6-4411
EXT. 7133

Conducting Agency: Proving Ground Department
Sandia Corporation

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* See "Remarks" on Page 6.1.4

Object of the Experiment:

A complete understanding of blast phenomena involves many problems - very few of which can be adequately treated with theoretical methods alone. To the bomb design theoretician, knowledge of the free-air* pressure field that would be established in a homogeneous atmosphere by a given atomic explosion is sufficient. Such knowledge would imply an understanding of how the explosion energy is partitioned (between the various energy transport mechanisms) and how at least part of that energy is propagated. In the strict sense, the phrase "field variable" means just that when applied to pressure. Since no such homogeneous atmosphere exists, however, and we see that pressure can never be studied as a field variable in the strict sense, it seems logical to study pressure fields that have been perturbed only by atmospheric inhomogeneities. The discussion of Project 6.2 is devoted to explaining the proposed contributions of Operation IVY to such studies.

The next step in complexity involves studying the pressure field, near a reflecting surface, in order that one may understand how such a surface perturbs the field - as a function of pressure, time, characteristics of the reflecting surface, and characteristics of the atmosphere above the surface. This project is designed to augment the existing fund of experimental data on the latter - by measuring pressure as a function of time, on or near the earth's surface, at various fixed points around Eniwetok atoll for shots MIKE and KING. The value of such data to those interested in Weapons Effects is clear, since most objects that one might wish to destroy with (or protect from) an atomic bomb are located on or near the surface of the earth.

Method and Procedure:

A. One device which measures the instantaneous incident pressure is known as a Wiancko gauge. This instrument makes use of the pressure-induced deformation of a twisted "bourdon" tube to vary the inductance of a coil - thus generating an electric signal, the magnitude of which is proportional to the instantaneous value of the incident pressure. A permanent record of the signal is made electronically, either on magnetic tape, photographic film or paper. Each gauge thus supplies a record of pressure versus time at its location - and a pressure versus distance record is obtained by placing gauges at a number of different positions.

To obtain information as to azimuthal variations in the field, gauges are located on different radial lines from zero. To separate "surface" effects from the records, the gauges are mounted a few feet above the ground on small towers. When the latter is not feasible, the

* See the discussion of Project 6.2.

gauges are mounted flush with local surfaces (ground baffles).

B. For MIKE shot, Wiancko air pressure gauges will be placed at thirteen positions around the eastern side of the atoll, as follows:

Station Number	Island	Dist.from Zero (ft.)	Type of Gauge Mount
614	Teiteiripucchi	4422	Ground baffle
615.01	Bogairikk	5900*	Ground baffle
616.01	Bogairikk	5900*	Ground baffle
615.02	Bogon	8250**	Ground baffle
616.02	Bogon	8250**	Ground baffle
610	Site Noah***	11490	15 foot tower
611.01	Engebi	15900	15 foot tower
611.02	Muzin	21412	15 foot tower
611.03	Bokon	30130	15 foot tower
611.04	Aomon	47574	15 foot tower
612.01	Parry	-	15 foot tower
613.01	Aitsu	-	10 foot tower
613.02	Runit	74884	10 foot tower

In this way, an estimated peak pressure range of from 0.8 to 300 pounds per square inch (psi) will be covered. The recording will be accomplished in the following stations:

Station Number	Island	Type of Structure
600	Bogon	New concrete blockhouse
601	Engebi	GREENHOUSE station 301J
602	Muzin	" " 301H
603	Bokon	New concrete blockhouse
604	Aomon	GREENHOUSE stations 132a & b
605	Runit	" " 55
606	Parry	New wooden blockhouse

In every case, signal wiring is being kept to a minimum, both by recording at the nearest available recording station and by careful selection of gauge locations.

* Different radial lines.
** Different radial lines.
*** This is a small artificial island on the reef between Bogon and Engebi.

For KING shot the same type of gauge will be used, and two measurement lines will be established - one over water and one over land. For the former, the gauge mounts will be 15 foot towers, located at 2500, 3000, 4000, 5000, 6000, 7000, 10,000, and 15,000 feet from bomb zero. The line will extend along the reef to the south, an attempt being made to keep each instrument at least one hundred yards from land - in order that the measurements may be more nearly "over water". The land line will be established on Runit, and will consist of the following:

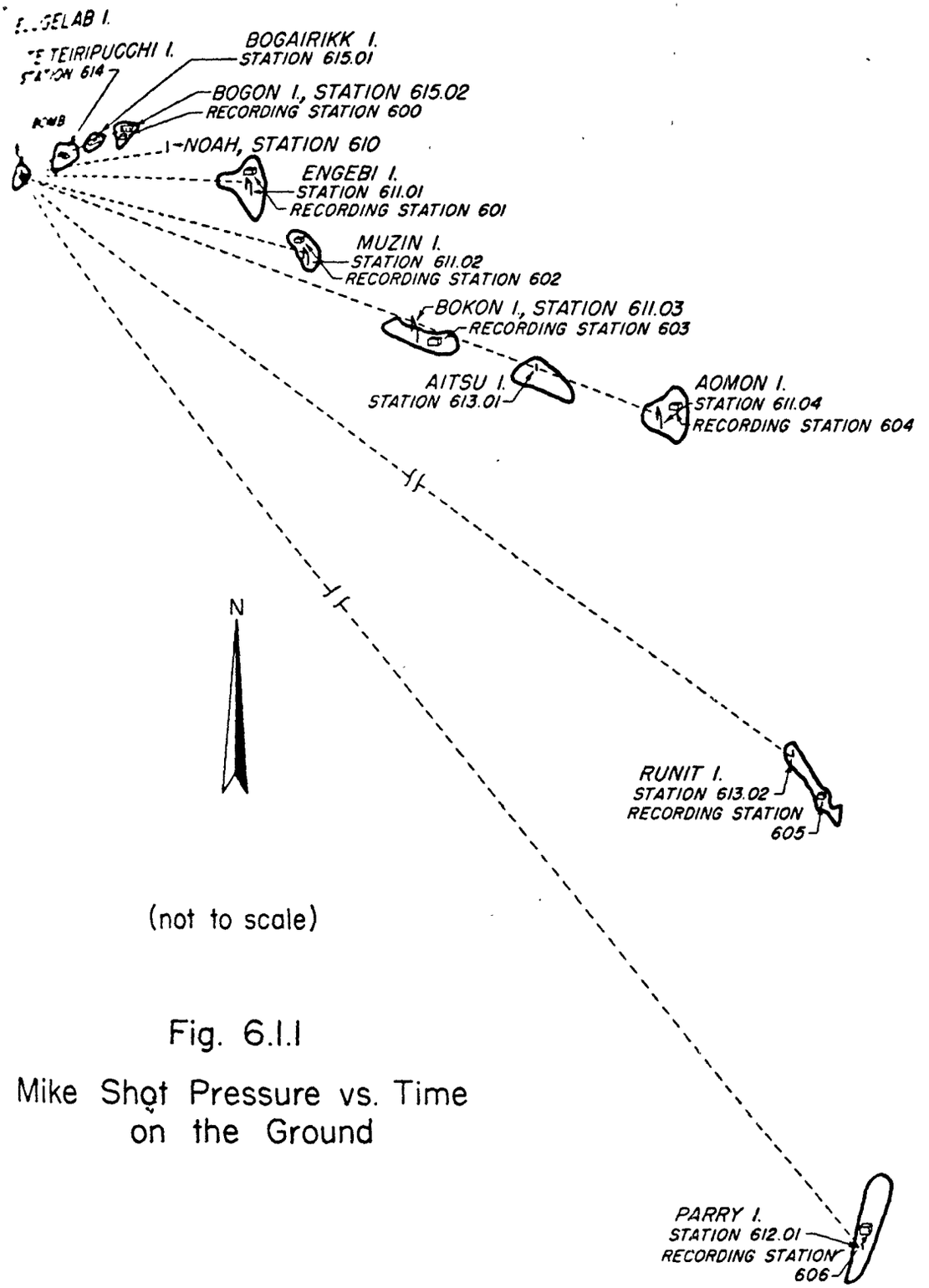
Station Number	Distance from Zero (ft.)	Type of Gauge Mount
6101.01	3000	Ground baffle
618	5000	15 foot tower
6101.02	5000	Ground baffle
619.01	7000	15 foot tower
6101.03	7000	Ground baffle
619.02	9678	15 foot tower
6101.04	9678	Ground baffle

Recording of these measurements will be accomplished in station 605. In addition to the above, one gauge will be mounted (on a 15 foot tower - station 612.02) on Parry - the measurements of which will be recorded in station 606.

Remarks:

The Proving Ground Department of Sandia Corporation is responsible for four distinct projects (6.1, 6.3, 6.5, and 6.7b) of the Blast Measurements program. The work loads imposed by these projects, however, are not separable. As a result, the Sandia Corporation personnel under Mr. Lenander's supervision will devote their efforts to all projects equally. In lieu of listing personnel requirements for the individual projects, the following table is presented; to represent the total proposed forward area requirements for the above mentioned four projects:

Officer	Enlisted	Civilian	From	To
		2	M-130	M/7
		1	M-99	M/7
		3	M-59	M/29
	12	21	M-44	M/29
		2	M-14	M/25

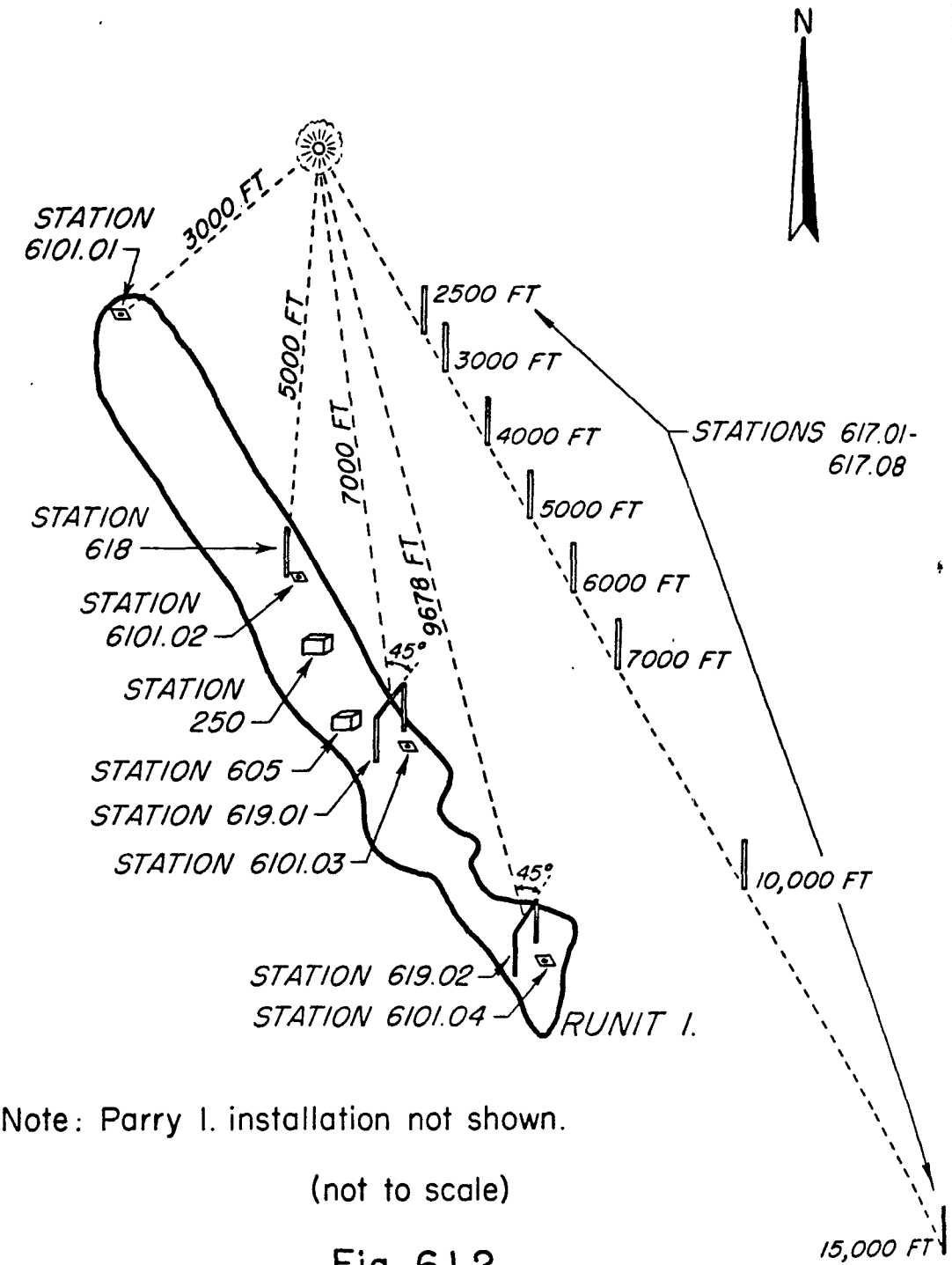


(not to scale)

Fig. 6.1.1

Mike Shot Pressure vs. Time on the Ground

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Note: Parry I. installation not shown.

(not to scale)

Fig. 6.1.2
King Shot Pressure vs. Time on the Ground

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.2 Project Title: Air Mass Motion Studies

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Lt. Col. Francis B. Porzel
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2766

Conducting Agency: Group J-10
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-60	K/15
Enlisted	6	"	"
Civilian	1	"	"

Support Required:

Object of the Experiment:

One of the most perplexing problems in the field of atomic weapons effects is the obtainment of an accurate and complete free-air over-pressure versus distance curve. By complete we mean a continuous record of pressures from the relatively high (hundreds of pounds per square inch) to the very low (a fraction of a pound per square inch). Over-pressure, of course, is defined as absolute pressure less ambient pressure - and the term free-air implies the true absolute pressure existent at a point in the atmosphere, in the absence of such perturbing factors as measuring instruments, structures, aircraft, or the earth's surface.

Unfortunately, the hydrodynamical equations which describe this phenomenon completely can be written but not solved. An approximate solution has been obtained with IBM machines, under the simplifying assumptions of a homogeneous atmosphere and no radiative transport of energy - this solution, however, is of maximum value only when supplemented with experimentally determined facts, as it tells us nothing about the attenuation of the shock strength with passage to altitude.

The obtainment of such experimentally determined facts is fraught with difficulties, as will be seen from an examination of our definitions above. First one must develop an instrument which will document the passage of the shock wave without disturbing that passage in any way, otherwise the measurements will not be true "free-air". Then a system must be evolved for fixing these instruments at known positions in space.

The importance of having the above mentioned pressure versus distance curve cannot be overemphasized. For instance, in the field of atomic weapons effects alone, the correct answers to the following questions would come much closer to being a reality:

(1) What is the minimum safe target approach distance for a dropping aircraft, as a function of target altitude, aircraft altitude, and energy release of the weapon?

(2) What accuracy is required for the optimal use of atomic warheads in anti-aircraft projectiles, as a function of target altitude, target velocity, probable target dispersal (tactical deployment of aircraft formations), and energy release of the warhead?

(3) What is the optimal bomber formation for effective deployment against an enemy target which may be defended by atomic anti-aircraft projectiles?

At the present time, these questions (and many others, closely related) can be answered in an approximate way only - by making many simplifying assumptions. The availability of good free-air pressure versus distance information will decrease the number of those assumptions by at least one. This experiment attempts to supply some of this information, by employing an "ingenious device" to partially circumvent the experimental difficulties mentioned above.

Method and Procedure:

A. One method of labeling the atmosphere is supplied by smoke puff photography. A puff of smoke is placed in the atmosphere - in some region of interest (the placement procedure will be discussed below). A motion picture camera has been previously aligned in such a way that the puff is well within its field of view, and the camera has been supplied with a device for placing timing "pips" on the film. Subsequent photography of the puff, and film analysis procedures, will supply the experimenter with a time history of the puff's motion and perturbation.* Use of one camera, of course, will only document the projection of the puff on a plane perpendicular to the axis of the camera. If one places the puff in a known plane initially, however, and makes wind corrections, a reasonable approximation to the three dimensional path of the puff can be obtained.

Such a method should supply us with the following information, with fair accuracy:

(a) The elapsed time from zero to the arrival of the shock at the puff. This combined with the Eulerian coordinates of the puff at that time (obtained from film analysis) will supply a point on the free-air shock time of arrival curve.

(b) The motion of the puff after passage of the shock. Such "mass motions" are theoretically associated with the variation of shock strength with time, and hence with the variation of shock overpressure with time in that region. This represents the primary measurement of the project.

* The puff itself may be thought of as a point in the Lagrangian coordinate system, and the technique outlined herein is a method of associating this Lagrangian point with both time and the Eulerian coordinate system.

B. For MIKE shot, low altitude (~ 400 feet) labeling of the air will be accomplished with exploding mortar projectiles. The distances from zero will be similar to those chosen for the Wiancko gauges of Project 6.1 - the actual positions, however, are quite different. Most of the mortars will be mounted on ten foot square rafts and placed in the lagoon, to allow photography from stations on the eastern side of the atoll. The four close-in mortars will have their firing mechanisms actuated with EG&G timing signals - the remainder will be actuated by means of "blue boxes". The mortar-produced puffs will be photographed by ten Mitchell (100 frame/sec) cameras - from vantage points on Engebi, Rojoa, Runit, and Parry. These cameras will be mounted in individual shielded steel boxes on concrete pillars.

In addition, the air will be labelled with smoke at ten altitudes above the bomb (5000, 6000, 10,000, 11,000, 15,000, 16,000, 20,000, 21,000, 25,000, and 26,000 feet) by means of bursting shells from guns. The guns will be placed on Engebi, and the bursts will lie on a line defined by the intersection of the following planes:

(1) A plane such that a horizontal line in that plane is perpendicular to the line from zero to the photo station on Rojoa. This plane makes an angle of 60 degrees with the horizontal, passing through zero and leaning toward Rojoa.

(2) A plane such that a horizontal line in that plane is parallel to the line from zero to the Rojoa photo station. This plane makes an angle of 75 degrees with the horizontal, passing through zero and leaning toward Bogollua.

The ten guns will be placed on Engebi, each gun assembly being mounted on a concrete pad (10 feet square and 8 inches thick). Since the lowest burst height is 5,000 feet, the choice of the above line (along which the bursts will lie) implies that no gun is aimed toward the bomb. If the velocity of a projectile be wrong, the nearest possible approach to the bomb is 1,000 feet. All guns will be fired with timing signals furnished by EG&G. The gun-produced puffs will be photographed by five Mitchell (100 frames/sec) cameras, from the photo station on Rojoa.

For KING shot, only the low altitude (~ 400 feet) air labeling technique will be used. Eight mortars will be placed on a line running approximately northwest from ground zero - the nearest being at 4,000 feet and the most distant being at 15,000 feet. The puffs will be photographed by Mitchell cameras from the Rojoa photo station.

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Remarks:

1. A fundamental difficulty with this measurement is the fact that cloud coverage may result in complete failure to obtain data. Since this method is the simplest known way to obtain the information sought, however, it is felt that the chance is worth taking.

2. It should be clearly understood that high orders of accuracy in the obtainment of free-air pressure information are not essential to the present day "effects on things" planning. This is due to the fact that the response of the "things" to those pressures is not well understood. Such a fact, however, does not preclude the desirability of understanding the pressure field about an atomic bomb explosion as completely as possible. Future developments in the field of structural analysis may well make highly accurate pressure knowledge necessary.

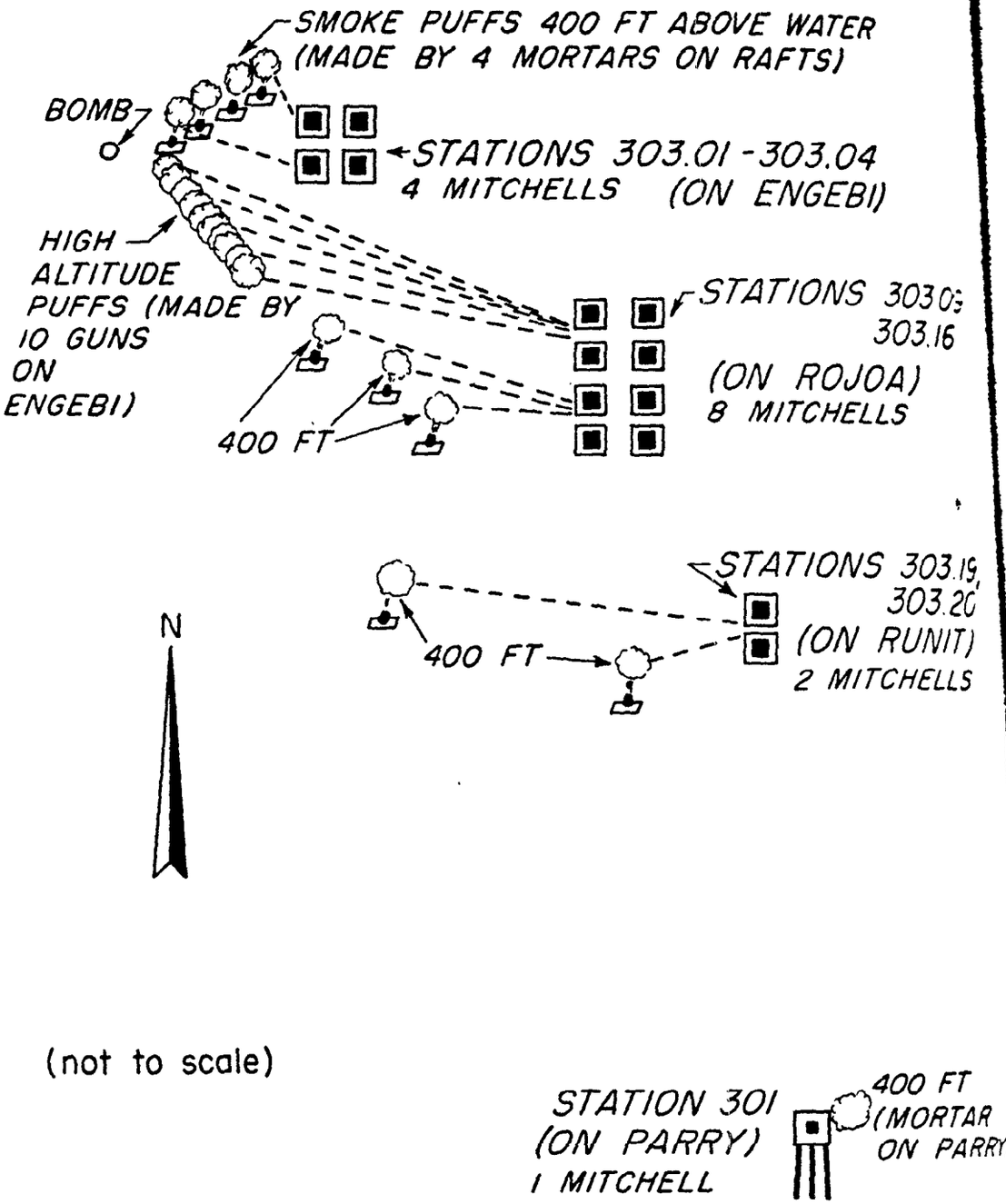
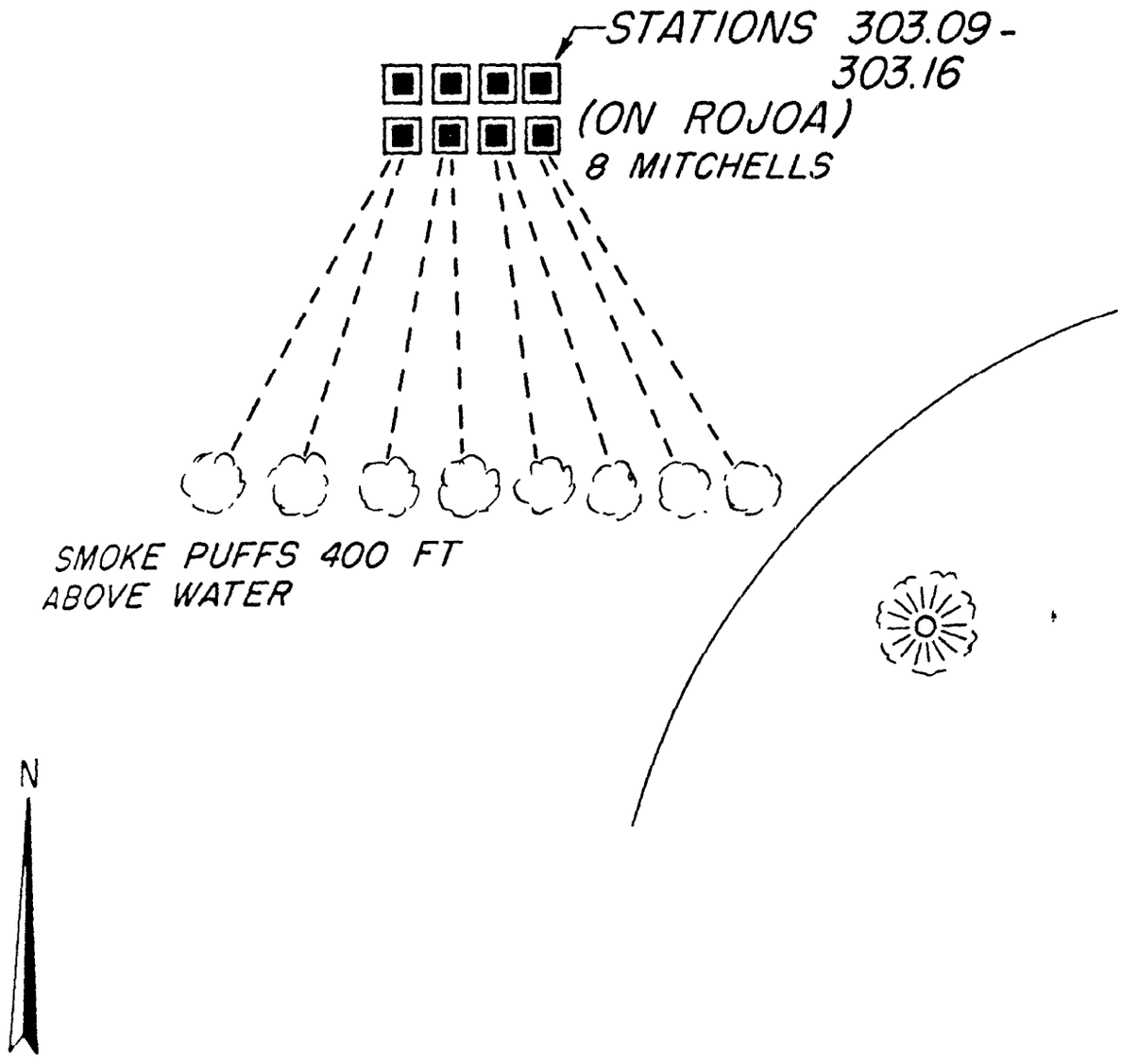


Fig. 6.2.1
Mike Shot Air Mass-Motion Studies

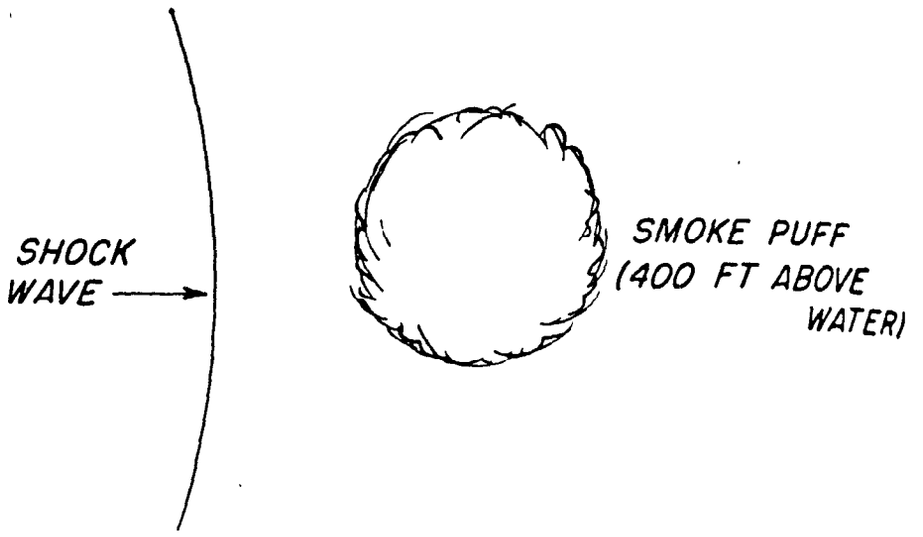
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(not to scale)

Fig. 6.2.2

King Shot Air Mass-Motion Studies



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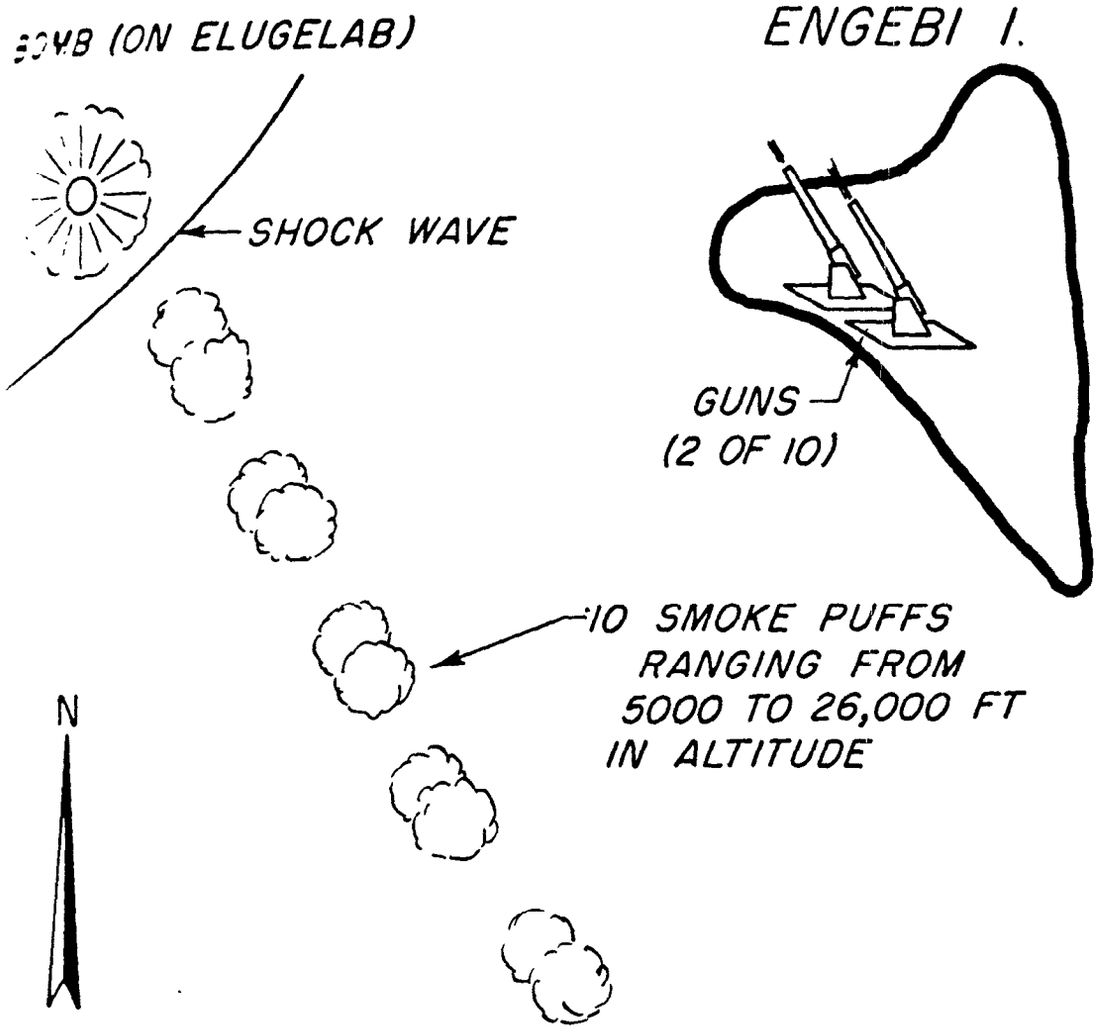


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Fig. 6.2.3
Detail for Low Altitude Smoke Puffs

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(not to scale)

Fig. 6.2.4
Detail for High Altitude Smoke Puffs

PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.3

Project Title: Shockwind, Afterwind, and Sound Velocity.

Type Participation: MIKE - KING

Sponsor: AEC

Project Officer:*

Name: Mr. Harlan E. Lenander
Address: Proving Ground Department
(Code 5230) Sandia Corporation
Sandia Base, Albuquerque, New Mexico

Phone: Albuquerque 6-4411
EXT. 7133

Conducting Agency: Sandia Corporation
&
Group J-10
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:**

	Approximate Number	From	To
Officer	1 (J-10)	M-45	K+7
Enlisted			
Civilian	1 (J-10)	M-45	K+7

Support Required:

* See "Remarks" on page 6.3.6

** See page 6.1.4

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Object of the Experiment:

The static pressure experienced by a fixed point in the blast field exhibits the following qualitative variation with time:

(a) Prior to shock arrival it remains relatively constant at its ambient value.

(b) Passage of the shock wave is accompanied by an abrupt pressure rise to some peak value. This peak value is determined in part by the distance from bomb zero and the energy release.

(c) After the shock passes the pressure falls (in something like an exponential fashion) with time from the above mentioned peak to below-ambient values. It subsequently passes through a minimum, and finally approaches the ambient value from below.

For a given point in space, the period during which the pressure is greater than ambient is known as the "positive phase" - and the period during which the pressure is below ambient is known as the "negative phase". The positive phase is characterized by a wind blowing radially outward (from zero) and the negative phase is characterized by a wind blowing radially inward toward zero. These are the shock winds. Material velocity behind the shock (one of the parameters entering into the equations used to describe shock propagation) is another name for the shock wind in that region.

The rising fireball creates a tremendous "updraft" in the vicinity of bomb zero. Such a vertical motion of an air column creates a low pressure region near the base of the column. This in turn causes outside air to flow into the lower portion of the column. The latter is called the "afterwind".* For a sufficiently small burst height (above the earth's surface), the above mentioned column rests on the ground - and the afterwind includes horizontal components at ground level, directed toward ground zero. The mechanisms which create an afterwind on the one hand and a "fire-storm"** on the other hand are essentially the same.

* The term "afterwind" may also be used to include the shock winds of the negative phase. In this case, the phrase "shock wind" applies only to the radially-outward winds associated with the positive phase.

** Similar to that following the Hiroshima detonation.

When an object is placed in a moving fluid, such as air, the pressure to which the object is subjected consists of two distinct components - the static pressure and the dynamic pressure. The former is the pressure that the object would "see" if it were moving with the fluid - the latter is the additional effective pressure on the object, produced by the fluid velocity. Which of these components is the larger depends on the particular conditions - and each is capable of destruction, as an inanimate object has no way of differentiating between them. Thus the above mentioned winds are potential destructive forces, and are worthy of study as such.

The ambient (unshocked air) sound velocity, the material velocity behind the shock, and the sound velocity behind the shock are all parameters which occur in theoretical shock wave descriptions. As a result, their experimental documentation for an actual wave is very valuable to a complete description of the phenomena associated with the wave.

The objectives of this project are thus seen to be two-fold, as follows:

(a) The measurement of shock winds and afterwinds at various distances from ground zero.

(b) The measurement of sound and material velocities, both prior to and after shock arrival, at various distances from ground zero.

Method and Procedure:

A. At this writing, feasibility tests of several instruments are being conducted at the NTS. Final decisions as to which of these instruments will be used for IVY will be forthcoming on or about 15 June. Among those instruments being considered are the following:

(a) A double-ended pitot head assembly. This instrument measures both total (static plus dynamic) and static pressures. It is made double-ended in order that both the positive and negative phase winds can be documented. Its mode of operation is identical to that of any aircraft pitot head.

(b) A so-called Sonic Interferometer. This instrument assembly consists of a pulsing mechanism, two sound wave generators, two receivers, a timing oscillator, an interval timer, and recording equipment. That portion of the assembly which actually is subjected

[redacted]

to the blast wave is mounted on the cross bar of a "goal post" type tower, some 15 feet above the ground. The two sound wave generators are located at the center, and one receiver is attached to each end, of the bar. The goal post is oriented in such a way that the bar makes a 45 degree angle with the oncoming blast wave. Hence one receiver is upstream, and the other is downstream, of the transmitter head. The remainder of the assembly (pulsing mechanism, timing devices, and recording equipment) is mounted in a nearby recording station, to and from which the necessary signals can be carried by wires.

In brief, operation of the above instrument is as follows:

(1) The timing oscillator (set for 250 signals per second) triggers the pulsing mechanism and the interval timer simultaneously.

(2) The pulsing mechanism feeds a pulse to the transmitter head, which in turn generates two sound waves.

(3) Upon detection of a sound wave, a receiver notifies the interval timer and its associated recording equipment.

The basic data obtained by the instrument consists of elapsed time measurements - from the electronic initiation of each signal to its recording after detection by both receivers. Calibration allows these measurements to be interpretable in terms of the sound wave transit times over both upstream and downstream air paths. The latter information can in turn be theoretically related to both local sound velocity and wind velocity.

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(c) Kiel-meters and Q-tubes. These instruments are commonly used for wind tunnel pressure measurements. Their operation is based on an application of Bernoulli's principle.

(d) A device known as the Sonic Anemometer, the name being derived from the fact that it is a wind velocity measuring instrument which probes the velocity field with sound waves. This interesting device, which was designed and developed by Group J-10, of LASL, measures the elapsed times between the creation of a sound wave

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(by a spark gap) and its arrival at two microphones. The path lengths in air (from spark gap to each microphone) are identical in length and oriented differently with respect to a radial line from bomb zero. The difference in wave arrival times, at the two microphones, is a measure of the relative motion of the air through which the wave passed - and hence of the local wind velocity. The time required for a wave to traverse a given path is a measure of the average sound velocity over that path.

A typical installation consists of a 24 inch (diameter) hole in the ground (16 feet deep) - around the mouth of which three steel pipes extend vertically some six feet above the ground. The pipes are located at the vertices of an isosceles right triangle, the altitude of which is perpendicular to a radial line from ground zero. The microphones are located at the tops of the pipes at either end of the triangle base, and the spark gap is located at the top of the pipe remaining. The air paths are thus the equal sides of the triangle - each being approximately one meter long. The electronic equipment, including a dual-trace recording oscilloscope, and a Warrick high speed camera which provides permanent records by photographing the scope face, are mounted in the hole - cheap shielding from ionizing radiation thus being obtained.

B. For MIKE shot, Group J-10 of LASL will measure both sound and inward directed wind velocities - using Sonic Anemometers. These measurements will start at the end of the positive phase (at a given station) and extend for approximately ten seconds. The instrument locations will be as follows:

Station Number	Island	Distance from Zero (ft.)
630.01	Engebi	19363
630.02	Kirinian	24104
630.03	Bokon	30764
630.04	Biijiri	51008

The possible participation of this group in the KING shot program is as yet unsettled.

The Proving Ground Department of Sandia Corporation, using one or more of the other instruments mentioned, will also measure sound and wind velocities for both MIKE and KING shots. Their instruments

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will be mounted on, and the recording for them will be done in, Project 6.1 stations* (15 foot towers and associated recording stations) - on Bogairikk, Bogon, Engebi, Muzin, Bokon, Aomon, Parry, and Runit. The two closest stations will not measure wind velocity directly, because of its great magnitude, but will measure pressure differences along a shaped surface - from which the wind velocity can be calculated. Shaped surface designs are not yet available, but they will probably be concrete walls 5 to 10 feet high and 20 to 30 feet long.

Remarks:

Major Jack E. Whitener, of LASL, is the Project Officer for the Sonic Anemometer portion of this experiment. For those interested in contacting him for additional details of his work, we offer:

Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2766

* This includes the Sonic Interferometer goal posts - stations 611.01, 611.02, 611.03, 611.04, 619.01, and 619.02.

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Fig. 6.3.1

Mike Shot Afterwind and Sound Velocity
(Sonic Anemometer Stations)

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.4a

Project Title: Water Wave Motion - Shallow Water - Photographic.

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Cdr. William D. Baker
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2766

Conducting Agency: Group J-10
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-45	M/1
Enlisted			
Civilian			

Support Required:

(1) Overseas shipment of floats.

(2) Small craft for laying floats.

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Object of the Experiment:

As a continuation of the studies outlined under Project 6.4b, this project is designed to document water surface motions within the lagoon.

Method and Procedure:

A. Both the wavelength and amplitude of lagoon water waves will be observed photographically. To make such a technique feasible, the water surface will be labelled with floats. Each float will be located within the fixed field of view of a Mitchell (~100 frames/sec) camera. Subsequent film analysis will allow the construction of a position-versus-time function for each float - and hence for those water surface points.

B. The fields of view of those Mitchell cameras arranged to observe mortar-produced smoke puffs (see Project 6.2) will include the water surface. Hence ten film records can be obtained for this project by the proper location of floats alone. In addition, to obtain further coverage, three Mitchells will have a primary mission of obtaining records for this project. The latter will be mounted in individual shielded steel boxes on concrete emplacements. One each will be located on Engebi, Runit, and Biijiri.

The above instrumentation will allow documentation of lagoon water surface motions in the vicinity of Parry, Runit, Rojoa, and Engebi.

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.4b

Project Title: Sea Waves.

Shot Participation: MIKE

Sponsor: DOD (ONR)

Project Officer:

Name: Willard Bascom
Address: Scripps Institution of Oceanography
La Jolla, California

Phone: Glencove 5-4214

Conducting Agency: Scripps Institution of Oceanography
(University of California)

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	12	M-15	M/2

Support Required: The conducting agency will use two of its own fleet type tugs. In addition, military support will be furnished by Joint Task Force 132 - for operations at and in the vicinity of Bikini atoll.

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Object of the Experiment:

MIKE shot is expected to produce rather substantial waves on the surface of the surrounding water. This project is designed to document:

(1) The characteristics of the waves produced (number, height, period, length, and velocity).

(2) The amount of blast energy being transferred into wave-making.

(3) The nature of propagation and refraction of seismic-like waves over large areas of ocean.

Although many experiments which give a reasonably good picture of explosion-generated waves have been conducted, they have been for comparatively uncomplicated conditions. The principal problem is to ascertain the means by which energy is transferred from the explosion to the water (the impedance match). Such a problem is particularly difficult in this case because we have no comparable experiments upon which to base an estimate. For example, the "Seal" experiments by Leech indicated that there is a second critical depth, close to the water surface, at which a remarkably high percentage of blast energy goes into wave energy. In fact, the use of near-surface explosions is a promising means of deluging an enemy beach prior to an amphibious assault. This would lead one to assume that the MIKE waves will be high. On the other hand, the fact that the actual explosion will be over land suggests a poor impedance match and a low transfer of energy to wave making. There are at least six means by which waves may be produced:

(1) The existence of a high pressure area of considerable duration over the water surface near ground zero will give an initial outward impulse to the surrounding water.

(2) The pressure and tremendous heat will create a crater, the collapse of which may cause a second wave to start outward.

(3) A submarine landslide may be started by the blast, resulting in a tsunami (tidal wave) which, though a secondary effect, might make large waves at a distance.

(4) The air-pressure wave travelling across the water surface may be accompanied by a water wave of equal velocity.

(5) There may be a mass of rock and material lifted from the crater which will fall back into the sea - thus creating waves.

(6) Because of the assymmetry of the situation, with the shallow

lagoon (150 ft.) on one side and the deep ocean (12,000 ft.) on the other side, it is probable that the water crater will be much larger on the ocean side and that its collapse may throw a great mass of sea water into the lagoon - thus creating a secondary wave source.

Another very important, and highly indeterminate, fact is that under such circumstances these waves are likely to be of low amplitude in the deep ocean but may peak-up very considerably upon arriving at distant shores.

The value to the sciences of geology and geophysics of instrumenting a controlled seismic sea wave, perhaps the only one in history, can well be imagined.

Method and Procedure:

Waves are to be measured at four general types of locations:

1. In Eniwetok Lagoon.
2. In the open ocean nearby (undisturbed).
3. On the shores of islands at moderate distances (subject to some refraction and diffraction).
4. At great distances which are highly modified by the configuration of the bottom and the juxtapositions of islands.

The following specific locations and instruments have been chosen which, it is believed, will give the most satisfactory records of such waves:

(1) On Eniwetok island a shore recording station will receive electrical impulses thru a submarine cable from a pressure pick-up in about 60 feet of lagoon water. This is a tried and true instrument combination which has been used successfully in the past for measuring ocean swell.

(2) To the north of ground zero there are no suitable (nearby) islands at which the above "standard" instruments can be used. It is necessary, however, to measure waves reasonably close to ground zero in deep water. For this, a radical departure from previous methods of instrumentation will be required. A deep-sea mooring which utilizes the tops of undersea mountains (at 26 and 72 miles) will be tried; these flat-topped seamounts rise from 12,000 feet of water to within 4,000 feet of the surface and are thus in comparatively shallow water. A taut-line mooring with an underwater buoy for a pressure pickup station, connected by slack line to a spar-buoy containing the recording elements, will be used. Although this scheme is as yet untested, we believe it will be successful; and the eventual value of such an instrument-placing technique in undersea warfare can scarcely be overestimated.

(3) An installation on the seaward side of the westernmost islands of Bikini atoll, similar to that at Eniwetok, is necessary to measure waves at the third type of location. Here the first record of shoaling waves will be taken; diffraction will be measured and perhaps some indication of energy transfer can be obtained. Bikini will also have shore-recording wave meters cable-connected to pressure pick-ups in shallow water.

(4a) In order to measure waves at greater distances (500 - 2000 miles) a simple water-level recorder will be used which can be mounted on existing pier pilings. This instrument measures the differences in elevation of the water surfaces in two adjacent pipes which are suitably damped to exclude low frequency waves. Such installations are planned for Hawaii, Truk, Wake, and Midway.

(4b) It is quite possible that the MIKE-produced waves will be picked up by the U. S. Coast and Geodetic Survey recording-tide gauges which are distributed throughout the Pacific islands; copies of their records will be requested for study.

The University of California wave recorders on Guam, although not tuned for exact frequency response, will almost certainly get some sort of a record. These instruments will be operated continuously during the time at which waves may arrive at Guam.

Remarks:

As an aid in correlating water wave motion (and formation) with atmospheric pressure variations, microbarograph measurements may be made at Truk, Guam, Midway, and Wake islands. Such measurements would determine perturbation pressures established in the upper atmosphere by the nuclear detonation.

Each station would consist of two microbarophones installed on a radial line from Elugelab - the phones being approximately two miles apart. Measurement of the elapsed time between signal arrival at the two observation points allows a calculation of the angle from which the signal is coming.

It was originally planned that the Proving Ground Department of Sandia Corporation would make these measurements. Economy considerations, however, make it highly desirable that the Scripps Institution of Oceanography take the responsibility for them as a part of the parent project. At this writing, a final decision on this matter was not available.

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.5

Project Title: Ground Motion - Seismic Measurements.

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Mr. Harlan E. Lenander
Address: Proving Ground Department
(Code 5230) Sandia Corporation
Sandia Base, Albuquerque, New Mexico

Phone: Albuquerque, 6-4411
EXT. 7133

Conducting Agency: Proving Ground Department
Sandia Corporation

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* See "Remarks" on page 6.1.4

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Object of the Experiment:

Of the total energy released by an atomic explosion, an indeterminate percentage is transported (radially outward from bomb zero) by the ground. The magnitude of this percentage is dependent upon the impedance match between the ground and the weapon during reaction time. For a high air burst, the impedance match is obviously poor, and the percentage is essentially zero. For a deep underground burst, conversely, it is 100%. Low air bursts, surface bursts, and shallow underground bursts represent intermediate situations.

The transport of this energy by the ground is evidenced by earth accelerations and resulting motions. Documentation of these as a function of distance from bomb zero may make possible the theoretical deduction of how much energy was ground-transported. This project is designed to supply such documentation. Data from the pre-shot seismic surveys and earth attenuation measurements of Program 11 will aid in the analysis and interpretation of results obtained herein.

Method and Procedure:

A. The basic instrument to be used for these measurements is a Wiancko accelerometer. An acceleration along the axis of the instrument causes unbalance of a mass-loaded lever arrangement. This in turn causes the inductance of a coil to be varied - which generates an electric signal. Laboratory and field calibrations allow the magnitude of the generated signals to be interpretable in terms of the instantaneous accelerations. These accelerations can be integrated; once to obtain velocity, and twice to obtain displacement.

Each measuring station will consist of three such accelerometers mounted in the ground, with mutually perpendicular measuring axes. The earth acceleration will therefore be measured in three components. The depth of the accelerometer mounts will depend upon local conditions - depth of the base rock foundation, if any, etc.

B. Measuring stations will be established on Parry, Biijiri, Bokon, Muzin, Engebi, and Bogon. Exact locations and individual station details are not available at this writing.

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.7a

Project Title: Underwater Pressures Across the Lagoon and in Deep Water.

Test Participation: MIKE

Sponsor: DOD (USN)

Project Officer:

Name: Mr. James W. Smith
Address: Office of Naval Research,
Code 418, Navy Department,
T-3/2515, Washington 25, D.C.

Phone: Liberty 5-6700
EXT. 6-4476 or 6-6967

Conducting Agency: Office of Naval Research
Bureau of Ships (USN)

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	6	M-60	M/15

Support Required: One P2V (or C-47) to carry airborne telemetering relay equipment. This will weigh approximately 300 pounds, occupy 16 cubic feet, and require one man to operate.

* Additional help will come from Scripps Institute of Oceanography personnel engaged on another project.

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Object of the Experiment:

This project is designed to supplement the data obtained by the Sandia Corporation under Project 6.7b, by making a limited number of peak water pressure measurements along a line from ground zero through the center of the lagoon. In addition, the pressure-time history of the underwater shock wave, in the deep water immediately outside the reef northwest of the shot island, will be obtained. The data obtained may be of importance in determining the energy "coupling" coefficient*, as well as in predicting the effects of similar releases of energy on underwater ordnance and on vessels.

Method and Procedure:

A. A minimum of four pressure measuring and recording systems ("Tuna Cans") will be moored below the surface of the deep water immediately adjacent to the reef northwest of Elugelab. Each buoy for supporting the pressure pick-up is a completely independent unit containing the necessary power supply and recording system for the pressure-time instrumentation. A complete unit will weigh approximately 7½ tons. Pressure gauges will be suspended from the mooring cable at various depths to 2000 feet. In addition, suitable mechanical underwater pressure gauges will be utilized.

B. Scripps Institute of Oceanography vessels will position and permanently moor the pressure measuring instruments and the "Tuna Cans" during their operation in the Eniwetok area; then retrieve the records, and later the units intact, after the shot. A team of approximately six Navy scientists who have been doing underwater explosion research will be organized to accomplish the field work and analyze the data from this project. They will be based on the Scripps vessels.

The three outermost "Tuna Cans" will have surface buoy telemetering equipment (seven channels each), the signals of which will be relayed, by an airborne pick-up and relay telemetering station, to a ship plotting station. The aircraft involved has been requested and will probably be a P2V, whose position at shot time will be more than 2000 feet above the evacuation fleet.

* This is the ratio of energy transferred into the water to total energy incident upon the water.

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Remarks:

The Sandia Corporation will place six underwater pressure gauges in the shallow water on the lagoon side of the shot island, under Project 6.7b, the data from which will be coordinated with the above.

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.7b

Project Title: Underwater Pressures - Along Reef.

Shot Participation: MIKE

Sponsor: AEC

Project Officer:

Name: Mr. Harlan E. Lenander
Address: Proving Ground Department
(Code 5230) Sandia Corporation
Sandia Base, Albuquerque, New Mexico

Phone: Albuquerque 6-4411
EXT. 7133

Conducting Agency: Proving Ground Department
Sandia Corporation

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* See "Remarks on page 6.1.4

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Object of the Experiment:

As a continuation of the underwater pressure field studies*, this project is designed to measure the pressure as a function of time in the shallow water of the lagoon. Various distances from bomb zero will be instrumented, in order that pressure attenuation with distance can be documented. These measurements are not considered worthwhile for KING shot. Since it is to be an air burst, one expects a poor impedance match between water and exploding weapon, with a correspondingly small amount of energy being transported by the water.

Method and Procedure:

A. The basic instrument to be used herein is a Wiancko gauge**. modified for underwater use.

B. These gauges will be placed in the lagoon, 1/4 to 1/2 mile from land. The actual locations will be off Parry, Biijiri, Engebi, and Bogairikk. Recording of the data obtained by these instruments will be accomplished in nearby Project 6.1 recording stations, using standard equipment.

* See Project 6.7a

** See the discussion of Project 6.1

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.7c

Project Title: Acoustic Pressure Waves in Water.

Test Participation: MIKE - KING

Sponsor: DOD (USN)

Project Officer:

Name: Mr. James W. Smith
Address: Office of Naval Research
Code 418, Navy Department
T-3/2515, Washington 25, D.C.

Phone: Liberty 5-6700
EXT. 6-4476 or 6-6967

Conducting Agency: Office of Naval Research,
Naval Electronics Laboratory,
Bell Laboratories

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer	None		
Enlisted	None		
Civilian	None		

Support Required: This project merely requires that existing stations be alerted to record, analyze, and submit a report on data obtained with their equipment.

* Normal SOFAR station complements.

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Object of the Experiment:

This project is designed to make special observations, at several SOFAR (Sound Fixing and Ranging) stations in the Pacific (and possibly Atlantic) area, of acoustic signals propagated in deep water. It is believed that the MIKE shot yield can be crudely estimated from the characteristics of the received signal. It was demonstrated during Operation SANDSTONE that the relative yields of shots XRAY, YOKE, and ZEBRA could be established in this fashion. The poor impedance match (between ocean mass and exploding weapon) characteristic of an air burst will probably preclude the reception (at great distance) of such signals for KING shot.

Method and Procedure:

A. SOFAR is a method of detecting, and recording the characteristics of, acoustic signals propagated in a water layer which is approximately 500 fathoms under the ocean surface in the Pacific and 700 fathoms under the surface in the Atlantic. The transmission of sound waves in this layer is extremely efficient, apparently because of a temperature inversion at that depth. In fact, for MIKE shot, it is expected that the signal will travel through the layer around the tips of both Cape Horn and the Cape of Good Hope.

B. Navy SOFAR and SOFAR Research Stations, presently operating in the Pacific and Atlantic areas, will be used for special observation and analysis of the acoustic signals received during the shot period of Operation IVY. Installation of new pressure pick-ups and recording systems is being expedited at these stations. A specially trained observer will be attached to the normal staff of each of two such stations, to insure that observations are properly made and to analyze the available data. No new SOFAR stations will be established.

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.9

Project Title: Air Density vs Time

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Major Pedro R. FlorCruz
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2766

Conducting Agency: Group J-10
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	2	M-46	M/14
Enlisted			
Civilian	1	M-46	M/14

Support Required:

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Object of the Experiment:

This project is designed to make special observations, at several SOFAR (Sound Fixing and Ranging) stations in the Pacific (and possibly Atlantic) area, of acoustic signals propagated in deep water. It is believed that the MIKE shot yield can be crudely estimated from the characteristics of the received signal. It was demonstrated during Operation SANDSTONE that the relative yields of shots XRAY, YOKE, and ZEBRA could be established in this fashion. The poor impedance match (between ocean mass and exploding weapon) characteristic of an air burst will probably preclude the reception (at great distance) of such signals for KING shot.

Method and Procedure:

A. SOFAR is a method of detecting, and recording the characteristics of, acoustic signals propagated in a water layer which is approximately 500 fathoms under the ocean surface in the Pacific and 700 fathoms under the surface in the Atlantic. The transmission of sound waves in this layer is extremely efficient, apparently because of a temperature inversion at that depth. In fact, for MIKE shot, it is expected that the signal will travel through the layer around the tips of both Cape Horn and the Cape of Good Hope.

B. Navy SOFAR and SOFAR Research Stations, presently operating in the Pacific and Atlantic areas, will be used for special observation and analysis of the acoustic signals received during the shot period of Operation IVY. Installation of new pressure pick-ups and recording systems is being expedited at these stations. A specially trained observer will be attached to the normal staff of each of two such stations, to insure that observations are properly made and to analyze the available data. No new SOFAR stations will be established.

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.9

Project Title: Air Density vs Time

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Major Pedro R. FlorCruz
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-2766

Conducting Agency: Group J-10
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	2	M-46	M/14
Enlisted			
Civilian	1	M-46	M/14

Support Required:

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Object of the Experiment:

In the discussion of Project 6.2 we pointed out the difficulty of measuring a blast parameter without perturbing the flow with the measuring instrument. We also indicated one approach to a solution of the problem posed by such a difficulty; namely, the "probing" of the blast field with particles so small that their presence in the flow would cause little or no perturbation. Under Project 6.3 we discussed a second approach to the solution - the use of sound waves to probe the field.

The probing method used herein is a continuation of the first approach, in that even smaller (than the smoke particles of Project 6.2) particles are used. This project is designed to document the air density at various fixed points in the blast field - prior to, during, and subsequent to the passage of the shock wave. Knowledge of the air density alone is insufficient to describe the shock wave development completely. Since all the blast parameters (pressure, temperature, density, velocity, etc.) are related theoretically by well substantiated expressions, however, the measurement of any one is useful in the determination of others. Also, if we measure more parameters than are necessary to make the equation system determinate, the obvious advantage of being able to cross-check our results is available to us.

Method and Procedure:

A. In addition to its function as a blast parameter, density controls the transmission properties of air - for both particulate and electromagnetic radiation. That is, the mean free path* of gamma-rays, neutrons, beta-rays (electrons), etc. in air is a function not only of their energy but also of the air density. In other words, the cross section** of air with respect to radiation of a given energy varies with air density. In particular, an increase of air density implies greater attenuation with distance (shorter mean free path - higher cross section) to radiation of a given energy level.

To accomplish its purpose, this project utilizes a device known as the Beta-ray Densitometer, the latter being designed to take advantage of the above mentioned variation of cross section with

* See page 8.1.3

** See page 4.2.2

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sity. In brief, its method of operation is as follows: A beta-ray source of known intensity is observed by a phosphor-photocell type of detector, the separation between source and detector being ~ 50 cm. An air density increase (decrease) over the path between source and detector causes a decrease (increase) in the intensity of beta radiation incident upon the phosphor - which in turn causes a decrease (increase) in the light output by the phosphor. The latter leads to a corresponding decrease (increase) in the current signal generated by the photocell. The current signal is used to perturb an electron beam in a cathode-ray tube, and the primary datum generated by the instrument is a photographic record of the tube face. Laboratory calibration of the assembly allows analysis of the above mentioned film to be interpretable directly as air density versus time along the path.

B. For MIKE shot, four Beta-ray Densitometers will be used, one on each of the following islands: Engebi, Kirinian, Bokon, and Aamon. The distances from bomb zero to these stations will be approximately 20,000, 25,000, 30,000, and 50,000 feet respectively.

At present, it is planned to use two densitometers for KING shot - both of which will be located on Runit. Detailed planning for this phase of the operation is not complete at this writing.

Remarks:

(1) The density versus time information obtained herein should be valuable as a data-interpretation aid for Project 5.2 (Gamma Intensity as a Function of Time). At a given instant of time the density contour between bomb zero and any fixed point in space will affect the gamma radiation incident upon the point. Hence humps or troughs in the gamma intensity versus time curves may be explainable in terms of shock wave position (and attendant air density variations) relative to the gamma detectors.

(2) For the primary data of the densitometer to exhibit high signal-to-noise ratios, the instrument must be located such that:

(a) The density variations experienced during and subsequent to shock passage are relatively high.

(b) The magnitude of the extraneous (to this experiment) light signals generated in the phosphor by incident gamma radiation and neutrons must be relatively small.

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Hence we must place the station so close to the bomb that the shock strength is not too low when it reaches the instrument, yet sufficiently distant that the gamma-ray and neutron flux will be adequately attenuated. For small weapons, these conditions are mutually exclusive - for large weapons the situation is much better. The reader interested in determining why this is true needs only to compare the expressions for gamma-ray intensity versus distance and shock strength versus distance. Because of the above, MIKE shot presents the best opportunity to date for using the densitometer technique, and excellent results are expected. The smaller yield of KING shot will make a less desirable environment - not sufficiently less, however, to preclude its inclusion in the experimental program.

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Fig. 6.9.1

Mike Shot Air Density vs. Time
(Beta - ray Densitometer Stations)

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PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.10

Project Title: Free-Air Pressure as a Function of Time (Manned Aircraft).

Shot Participation: MIKE - KING

Sponsor: DOD (USAF)

Project Officer:

Name: Lt. Col. Rodney Nudenberg
Address: Wright Air Development Center
Wright-Patterson Air Force Base
Dayton, Ohio

Phone: Kenmore 7111
EXT. 2-2226

Conducting Agency: Wright Air Development Center

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	18	M-30	K/5
Enlisted	60	M-30	K/5
Civilian	4	M-30	K/5

Support Required: One B-36D and one B-47B, with spare parts, to be furnished by Wright Air Development Center. Crews to be furnished by Strategic Air Command.

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Object of the Experiment:

To determine the free air pressure as a function of time using manned aircraft to position the measuring instruments in space, at altitudes significant to delivery aircraft. In addition, data on the dynamic structural response of aircraft will be obtained. The latter will be used as a basis for establishing structural design criteria, and for immediate use in planning delivery techniques for very high yield weapons.

Method and Procedure:

A. One B-36D and one B-47B aircraft will be instrumented for measurement of overpressures, induced loads (such as increased lift and structural strains in the wings and tail group), and the dynamic response of the complete airplane to the blast wave. Since the yield of MIKE shot may fall within broad limits, it will be necessary to instrument the aircraft with two distinct sets of pressure gauges to cover a pressure range of 0 to 10 psi. Strain gauges will be employed to determine deflections of individual aircraft components.

The data will be recorded on consolidated oscillographs with a total of seventy-two sensing channels. These data will be returned to the ZI for reduction and analysis. It is hoped that the final results will be useful for the establishment of criteria for tactical employment of currently available (or future) aircraft as delivery devices for high yield bombs.

B. The instrumented aircraft will orbit the zero point at a safe distance until just prior to the detonation, at which time they will turn so as to be flying directly away from ground zero at the time of detonation. These aircraft will be based at Hickam AFB, T. H., with the B-47B being phased in and out of Kwajalein.

The aircraft used, and results obtained, will be coordinated with those of Project 6.11. This project is also closely associated with Project 8.5, in that the thermal attenuation measurements are being made in the same aircraft. In addition, the B-36D will carry radar scope cameras for Project 9.4.

Remarks:

1. This project is a continuation of the previous work on the effects of blast upon aircraft, which has been conducted by the

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Massachusetts Institute of Technology under Air Force contract. Valuable data were obtained during Operation GREENHOUSE, and such results are reflected in the refined pressure-time and pressure-distance curves which are currently being used by the USAF for tactical planning. The positioning of all aircraft for IVY is being influenced by these curves.

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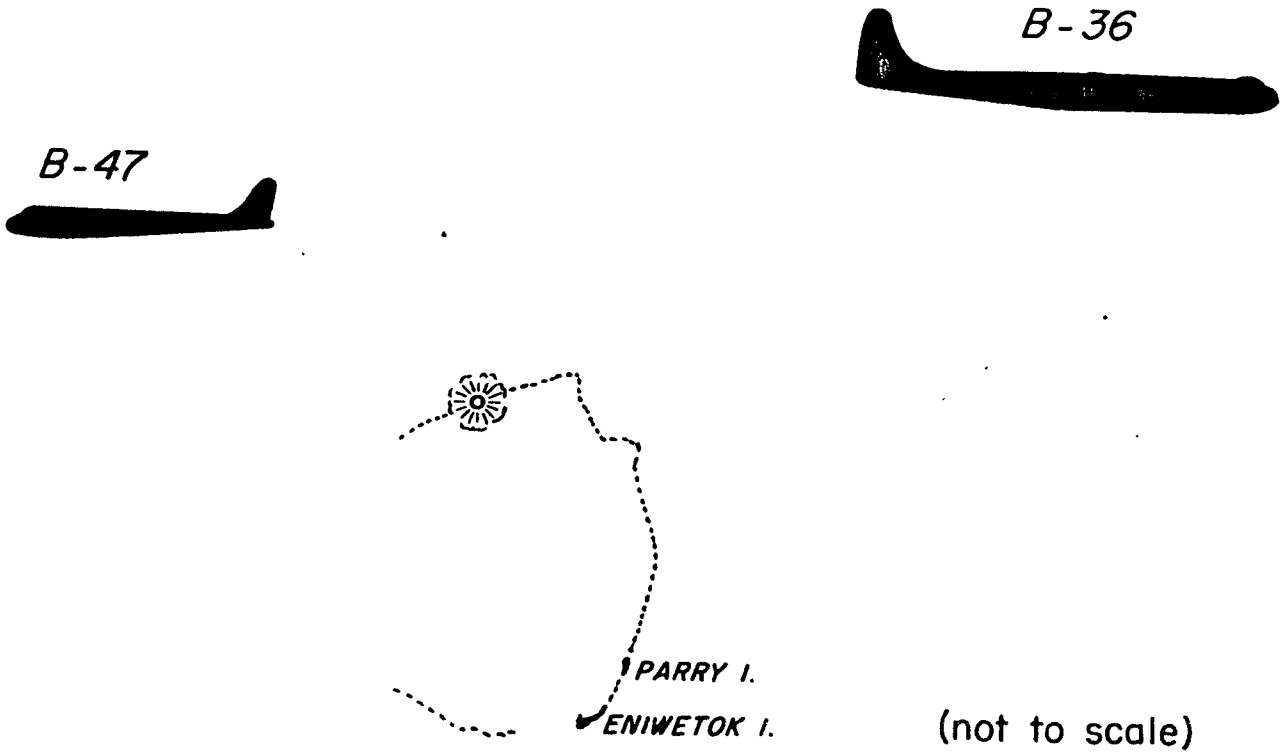


Fig. 6.10.1
Free Air Pressure as a Function of Time
(Manned Aircraft)

PROGRAM 6

BLAST MEASUREMENTS

Project No: 6.11 Project Title: Free-Air Pressure As A Function of Time Utilizing Parachute Suspended Canisters.

Participation: MIKE - KING

Unit: DOD (USAF)

Project Officer:

Name: Major James D. Vann, USAF
Address: Air Force Cambridge Research Center
230 Albany Street
Cambridge 39, Mass.

Phone: Lexington 9-2200
EXT. 69 or 133

Operating Agency: Air Force Cambridge Research Center (AFCRC) of the Air Research and Development Command (ARDC)

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	14	M-30	K+5
Enlisted	27	M-30	K+5
Civilian	18	M-30	K+5

Support Required: Two ARDC B-29's operating from Kwajalein, unless Hickam is a feasible operating base. ARDC crews will be provided, and the planes must be modified to allow pre-heating of canisters.

(Manned Aircraft)

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Object of the Experiment:

This project is designed to measure the free-air over-pressure versus time, at a number of different known altitudes and distances from an atomic bomb explosion. Data on the attenuation of a shock wave in a non-homogeneous atmosphere will be obtained to aid in the determination of safe (to flight crew personnel) procedures for aircraft delivery of high yield atomic weapons, and to verify (or deny) presently available theoretical approximation methods. In addition, free space thermal measurements will be obtained, under the conditions of severe reflection or absorption (due to cloud coverage) which may exist at shot time.

The effect of the ambient pressure and temperature gradients on a passing shock wave is almost completely unknown. Theoretical discussions of the effect exist, but there are no reliable experimental observations to test the resultant approximate theories. Such experimental data as do exist suggest that present theories are inadequate. The effects may be significant in determination of the optimum height of burst,* particularly for bombs of very large energy release. There is also an obvious application in the determination of minimum safe ranges and altitudes for dropping aircraft.

Method and Procedure:

A. For this project, the general plan of operation will be to obtain pressure and thermal measurements at twelve points along a radial line from the bomb - extending from the shortest range at which data can be obtained to approximately the operational range for manned aircraft. Twelve parachute-suspended canisters will be dropped on each shot, from two B-29 aircraft flying at approximately 32,000 feet. The altitude of the canisters at shock arrival time will vary from approximately 10,000 feet for the nearest to 30,000 feet for the most distant. The twelve instruments will be divided into two groups, one to give useful data in the event of a low yield and the other adjusted for documentation of a high yield. The two B-29's will each deploy six canisters, in such a way that a maximum of useful data will be obtained should either of the planes fail.

B. Each canister will contain a pressure sensitive element, a thermal sensing device, and a telemetering transmitter - it will be approximately 8 feet long, 14 inches in diameter, and will weigh 275 pounds.

* In the sense of maximizing the area subjected to a given peak pressure.

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The position of each canister is to be determined by an electronic system known as MOTS (Multiple Object Tracking System), which is being developed by the Glenn L. Martin Company of Baltimore, Maryland. There will be two such MOTS installations, one on the southern end of Eniwetok Island and one on Runit Island.

The airborne telemetering system was developed by the Bendix-Pacific Division of Bendix Aviation Corporation. Each canister utilizes three telemetering channels; one for an altimeter, one for a preselected pressure range, and one for thermal radiation data. A separate sub-carrier frequency will be frequency modulated by two additional signals - one from an ambient pressure transducer and one from a differential pressure measuring device. The sub-carrier frequencies are mixed and in turn frequency modulate the radio frequency carrier. The thermal radiation sensing device is a thermocouple (or an array of thermocouples) arranged such that a nearly hemispherical sensitivity pattern is achieved. The omnidirectional characteristic is essential as there is no control of canister aspect. The time constant of the thermal sensing element is to be as small as practical (considering the time available for development of the system) and will be of the order of .08 seconds. The output of the thermal sensing device is to be impressed upon the input of a saturable reactor modulation element of the Bendix telemetering system. The sensitivity of the various sensing elements will be adjusted to allow for the anticipated variation in radiation flux with distance.

The telemetering station consists of receivers, carrier discriminators, amplifiers, and recording instrumentation for each canister. It is planned to have this station on board a ship. Transmission range is 25 to 30 miles.

Remarks:

The system proposed for this project was proved during Operations BUSTER/JANGLE and TUMBLER/SNAPPER, and the instrumentation is almost fully developed. Detailed dropping procedures for the canisters are being established by AFCRC, WADC, and TG 132.4. For KING shot, particular emphasis is being placed on flight-coordination with the strike aircraft.

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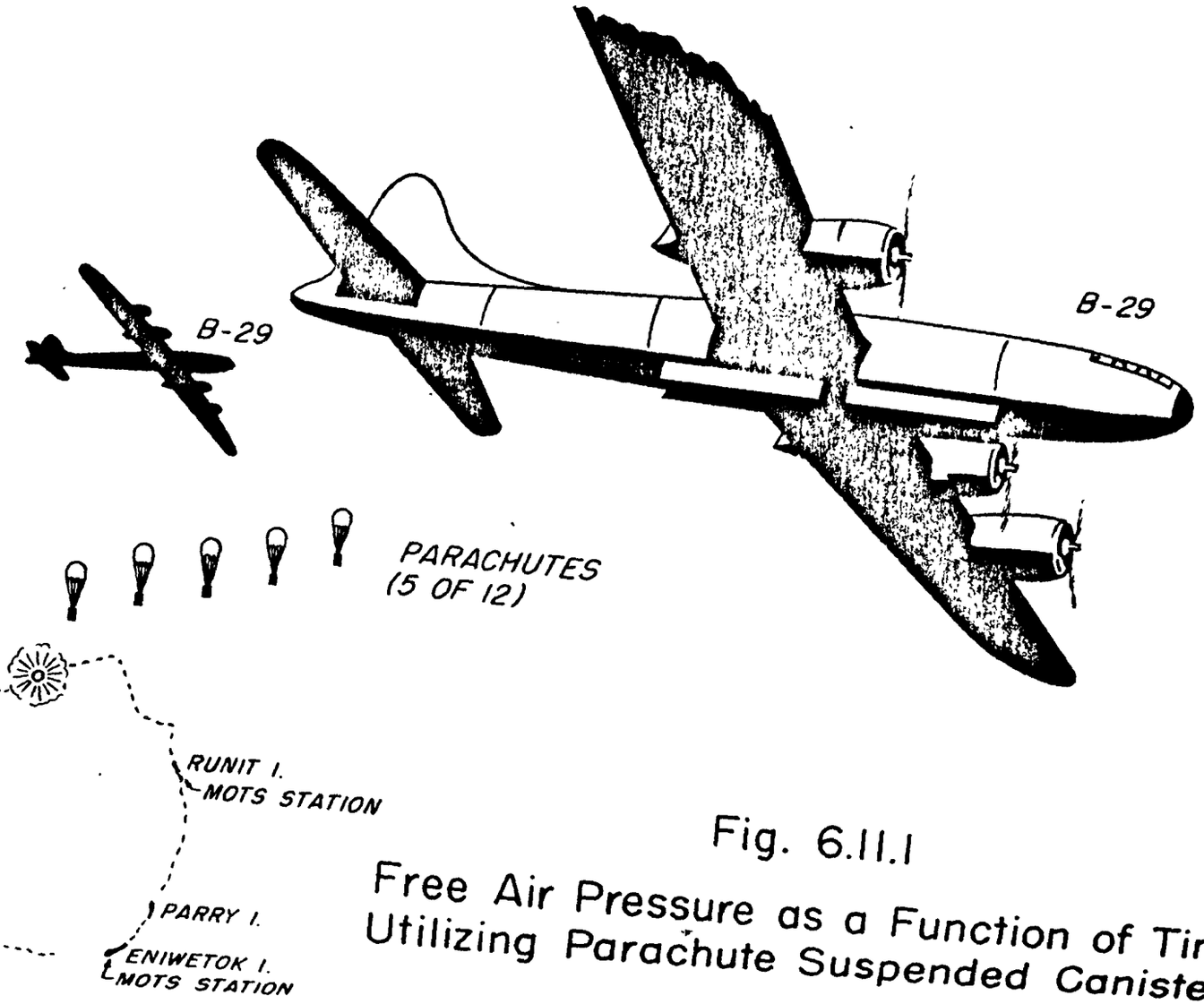


Fig. 6.11.1

Free Air Pressure as a Function of Time
Utilizing Parachute Suspended Canisters

PROGRAM 7

LONG RANGE DETECTION

Project No: 7.1

Project Title: Electromagnetic Effects From Nuclear Explosions.

Test Participation: MIKE - KING

Sponsor: DOD (USAF)

Project Officer:

Name:
Address:

DELETED

Phone:

Conducting Agency:

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	None		
Enlisted	None		
Civilian	None		

Support Required: Radio-transmitted timing signals.

ENIWETOK I. LMOTS STATION

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PROGRAM 7

LONG RANGE DETECTION

Project No: 7.2

Project Title: Airborne Low-Frequency Sound from Atomic Explosions.

Test Participation: MIKE - KING

Sponsor: DOD (USAF)

Project Officer:

Name:
Address

DELETED

Phone:

Conducting Agency

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	None		
Enlisted	None		
Civilian	None		

Support Required:

(1) Notification of each proposed shot time at H-24 hours.
(2) Notification of any change in schedule.
(3) Confirmation of each shot.
(4) Time of shot, to the nearest second (WWV world-time), as soon as possible after detonation.

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PROGRAM 7

Project No: 7.3

Project Title: Calibration Analysis of Close-In A-Bomb Debris.

Shot Participation: MIKE-KING

Sponsor: DOD (USAF)

Project Officer:

Name:
Address:

Phone: DELETED

Conducting Agency:

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	2	M-20	K+10
Enlisted	4	M-15	K+10
Civilian	4	M-10	K+7

Support Required:

Additional airmen for peak loads right after shot time may be needed when counting facilities are being operated twenty-four hours per day.

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PROGRAM 7

LONG RANGE DETECTION

Project No: 7.4

Project Title: Propagation of Seismic Waves.

Shot Participation: MIKE - KING

Sponsor: DOD (USAF)

Project Officer:

Name:
Address

DELETED

Phone:

Conducting Agency:

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	None		
Enlisted	None		
Civilian	None		

Support Required: Will require the time of detonation with relation to WWV world-time, with an accuracy of one-tenth (1/10) second, for each test in Operation IVY. This information will only be required "after-the-fact".

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PROGRAM 7

LONG RANGE DETECTION

Project No: 7.5

Project Title: Transportation of Airborne Debris.

Shot Participation: MIKE - KING

Sponsor: DOD (USAF)

Project Officer:

Name:
Address:

DELETED

Phone:

Conducting Agency:

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-25	K/10
Enlisted	None		
Civilian	None		

Support Required: Prompt transmission of cloud height and movement data to the Director, Program 7

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PROGRAM 7

LONG RANGE DETECTION

Project No: 7.6

Project Title: Detection of Fireball Light at Distances

Shot Participation: MIKE - KING

Sponsor: DOD (USAF)

Project Officer:

Name:
Address

Phone: DELETED

Conducting Agency:

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	None		
Enlisted	8	M-14	K+7
Civilian	1	M-14	K+7

Support Required: Timing signals similar to those specified for Project 7.1 will be required.

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PROGRAM 8

THERMAL RADIATION MEASUREMENTS

Project No: 8.1 Project Title: Integral Thermal Radiation.

Type Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. Harold S. Stewart
Address: Radiometry Section
Optics Division
Naval Research Laboratory
Washington 25, D. C.
Phone: Johnson 3-6600
EXT. 681

Conducting Agency: Radiometry Section
Optics Division
Naval Research Laboratory

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted	1	M-45	K/10
Civilian	2	M-45	K/10

Support Required:

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Object of the Experiment:

The thermal radiation emitted by an atomic bomb represents still another subject that must be thoroughly investigated. In the field of weapons effects, both personnel and materiel can be jeopardized by exposure to the tremendous flux of heat - especially under ambient conditions of low density and/or high visibility. The latter considerations, of course, being advantageous for the use of atomic weapons against aircraft - or disadvantageous if one happens to be using the aircraft as a weapon delivery device. In the fields of weapon design and diagnosis of weapon performance, on the other hand, detailed knowledge of every energy transport mechanism is essential to an understanding of how an atomic explosion actually develops - and thermal radiation acts as a highly efficient transport mechanism under certain conditions.

The experimental projects of Program 8 are devoted to a study of thermal radiation as a "field variable".* This project, in particular, is devoted to documenting the total (integral over time) thermal radiation received at various fixed distances from an exploding weapon. To further clarify the above statements, consider the equation:

$$Q = \frac{FY}{4\pi} \frac{T}{R^2} \qquad (8.1.1)$$

in which:

(1) Q is the total incident radiation, at a distance of R centimeters from the bomb, in calories per square centimeter.

(2) Y is the total energy release of the bomb in calories.

(3) F is the fraction of the bomb's total energy that is in the form of thermal radiation.

(4) R is the distance in centimeters from the bomb to the surface upon which the radiation is incident.

* See "preface".

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(5) T is that fraction of FY which reaches the surface under consideration - usually called the "transmission". A natural extension of this notation is the replacement of T by $e^{-R/\lambda}$ - where R is the same as above and λ is the mean free path* of the radiation for the particular medium (atmosphere) under consideration.

Equation 8.1.1 is not capable of theoretical justification as an exact description of the thermal radiation versus distance phenomenon. It does, however, appear to fit past data reasonably well - which is justification enough for its use in weapon effects planning. The knowledge of how thermal radiation affects things is sufficiently vague that an approximation device (such as the above equation) is quite adequate for the effects people.

The above equation is useful to the extent that we can determine F and T (or equivalently, λ) as functions of Y and the ambient atmospheric conditions respectively. This project is concerned with the determination of Q in equation 8.1.1, as a function of R, for both MIKE and KING shots.

Method and Procedure:

A. Two methods will be employed to measure total incident thermal radiation. The first of these is the conventional ballistic thermocouple technique. The output of an Epply thermopile is recorded by a GE photoelectronic galvanometer. The thermopile is essentially an electric current generator, the amount of current generated being proportional to the heat energy "seen" by the instrument - and a galvanometer is an electric current "sensing" device. Laboratory calibration of such a combination of devices allows the galvanometer reaction to be interpretable directly in terms of calories per square centimeter at the instrument.

The second method involves the use of so-called "black balls". For IVY, these will consist of black containers filled with some liquid - the color black being chosen to maximize heat absorption. The heat-induced expansion will move a diaphragm, and the motion of the latter will be recorded through a stylus linkage on a spring driven revolving drum. Laboratory calibration will again allow the peak expansion of the liquid to be interpreted as so many calories of heat per square centimeter falling on the instrument.

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* Defined as the distance (in the same units as R) over which the radiation must travel in order to be attenuated by a factor of e. (e = 2.718···, the base of natural logarithms.)

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B. For MIKE shot, six ballistic thermocouples will be operated - two from the Parry photo tower, two from station 801 on Engebi, and two from station 803 on Biijiri. In addition, "black ball" stations will be placed on Biijiri, Bogallua, Aitsu, Bokon, Kirinian, Engebi, and Bogon islands - and still another will be placed on a piling between Engebi and Bogon (at site Noah, a small artificial island).

For KING shot, six thermocouples will be used - two on the Parry photo tower, two in station 803 on Biijiri, and two mounted on a 12 x 12 foot platform (25 feet high) on Aniyaanii. In addition three "black ball" stations will be established near the north end of Runit. Each "black ball" station will consist of a pressure-tight case roughly two feet square and three feet high, to the top of which one or more balls (6" diam.) will be attached. The case will then be either buried (with the balls protruding above the surface of the ground, of course) or bolted to a concrete emplacement.

Remarks:

The tremendous amount of dust thrown up by a surface burst implies a strong variation of transmission with azimuth angle - and also the possibility of variations along a given radial line. As a result of this, one cannot be certain of adequate documentation of the total thermal radiation with a given number of measuring stations. In any event, the MIKE shot measurements will be characteristic of the weapon design, and of Eniwetok and the firing conditions - and hence may be of little use in predicting thermal effects from thermonuclear weapons in general.

The relatively dust-free light paths from an air burst are conducive to much more reliable documentation, hence the KING shot measurements may well be sufficiently complete and reliable to allow predictions to be made. The results of these measurements, when combined with past work on smaller yield bombs, will make air drop data available over the yield range of 1-500KT.

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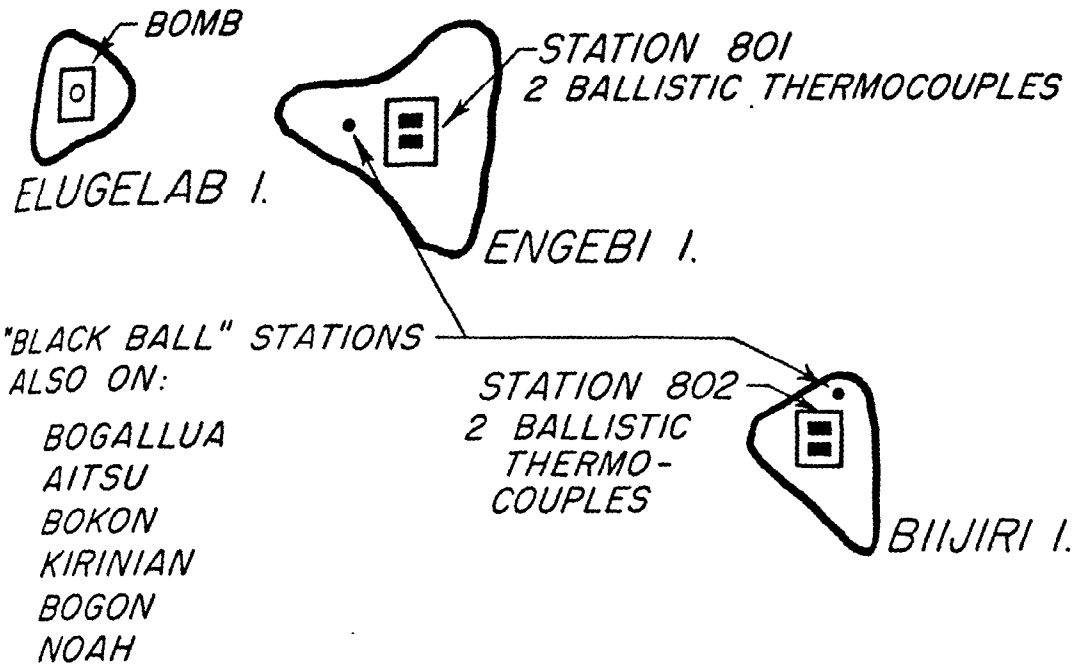


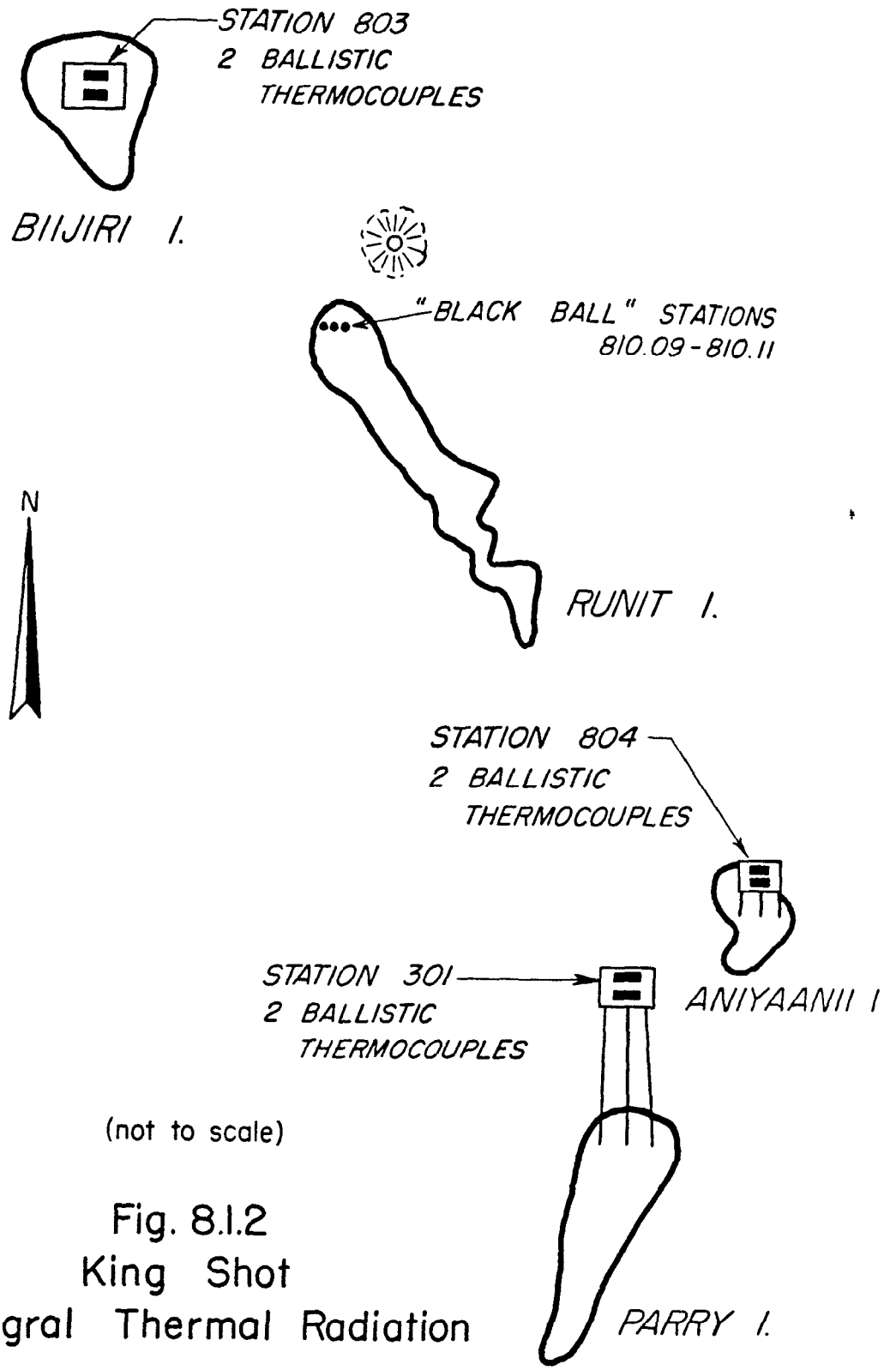
Fig. 8.1.1

Mike Shot

Integral Thermal Radiation

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(not to scale)

Fig. 8.1.2
King Shot
Integral Thermal Radiation

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PROGRAM 8

THERMAL RADIATION MEASUREMENTS

Project No: 8.2

Project Title: Thermal Intensity as a Function of Time.

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. Harold S. Stewart
Address: Radiometry Section
Optics Division
Naval Research Laboratory
Washington 25, D. C.
Phone: Johnson 3-6600
EXT. 681

Conducting Agency: Radiometry Section
Optics Division
Naval Research Laboratory

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-45	K/10
Enlisted	2	M-60	K/20
Civilian	2	M-45	K/10

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Support Required:

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Object of the Experiment:

To the soldier who may be exposed to thermal radiation from an exploding atomic bomb, perhaps the most important single question to be answered is "Can I duck it? - Is it possible to escape a large portion of its harmful effects by jumping behind a tree or rock, etc.?" To obtain the answer to such a question, we must investigate the time dependence of total thermal radiation.

To the weapon diagnostician, the early time dependence of thermal radiation is closely related to the fireball opacity and to the blast propagation near reflecting surfaces. Also, of course, it is important to the understanding of thermal radiation itself as a field variable. As an illustration of the latter, it can be combined with the spectrum versus time data to aid in the documentation of transmission* as a function of energy and atmospheric conditions.

Method and Procedure:

A. At IVY, three methods of measuring total thermal radiation versus time will be used,as follows:

(1) High speed bolometers, having approximately 25 μs time resolution, will be used to cover the period of time from just before to several seconds after zero - when the thermal radiation flux has returned to background values. The bolometer consists essentially of a small piece of blackened platinum wire that is exposed to the thermal radiation source, by means of a rotating chopper wheel, several thousand times each second. As the temperature of the platinum wire changes, its resistance changes - hence it is capable of supplying a signal to an electronic recording circuit, the magnitude of the signal being proportional to the temperature it "sees".

The bolometer assembly for this project consists of two such bolometers connected in push-pull electronically. Connected in this fashion, they generate a 24000 cycle AC signal, the amplitude of which is proportional to the radiant flux incident on the equipment. This AC signal is recorded on magnetic tape, using techniques which allow a dynamic range of one thousand times background (with a linear portion for 600 times background).

(2) Liquid flow meters, having a time resolution of approximately 1 ms, will be used to cover the same period of time as the

* See the discussion of Project 8.1.

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bolometer assemblies above. These meters have the advantage of being non-electronic (requiring no timing signals or power), and consist of a rigid chamber filled with an opaque liquid. A quartz window is placed in one wall of the chamber, through which the radiant flux may reach the liquid. This flux heats the liquid, with resultant expansion - and the rate of expansion is proportional to the rate of heating. In fact it can be shown that, to a fairly high degree of accuracy, the rate of flow (escape) of liquid from such a chamber is proportional to the rate at which radiant energy enters the quartz window. For this instrument, the rate of flow will be recorded on a revolving drum.

(3) For very early time coverage (0.1 μs to 100 μs), photocells will be used. These are nothing more than current generators having extremely good time resolution. The instantaneous current generated is a known function of the instantaneous radiant flux "seen" by the cell, and the known function is supplied by laboratory calibration. The current signals supplied by these instruments will be converted to voltage signals, attenuated if necessary, and recorded by oscillographs.

B. For MIKE shot, stations 800 on Engebi and 803 on Biijiri will each contain the following thermal radiation versus time measuring equipment:

(1) Two high speed bolometer assemblies.

(2) Two photocell recorders - one sensitive to the violet portion of the spectrum, and the other sensitive to the red portion.

(3) One or two of the above mentioned non-electronic instruments.

For KING shot, station 803 on Biijiri will be reactivated to take the same measurements as mentioned above for MIKE. In addition, these measurements will be duplicated from the 25 foot tower on Aniyaanii.

Remarks:

Contamination due to MIKE may make station 803 on Biijiri unavailable for KING shot thermal radiation measurements. If this should be the case, the Aniyaanii station will be depended upon for all time dependent total thermal measurements. Such a situation increases the probability of loss of data because of localized cloud cover.

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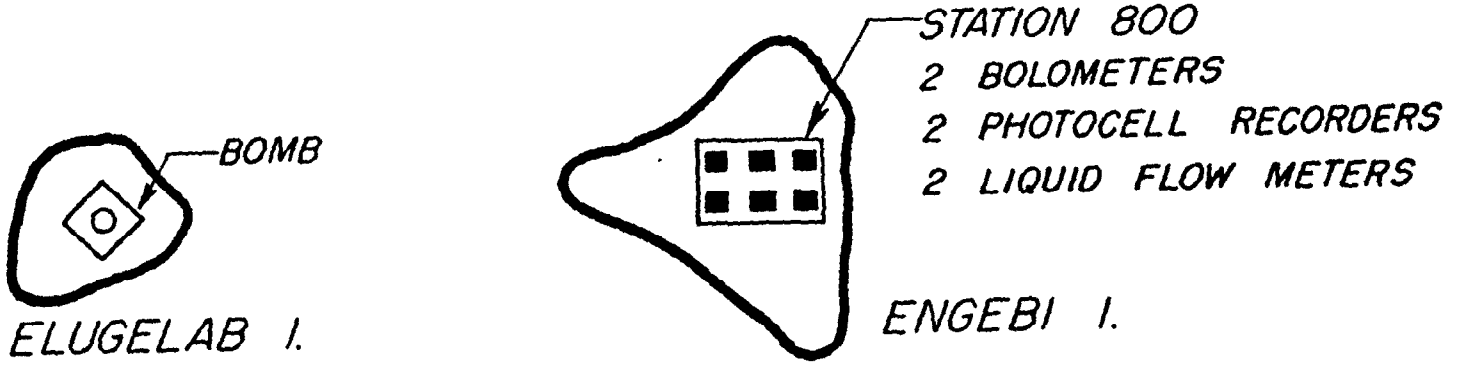
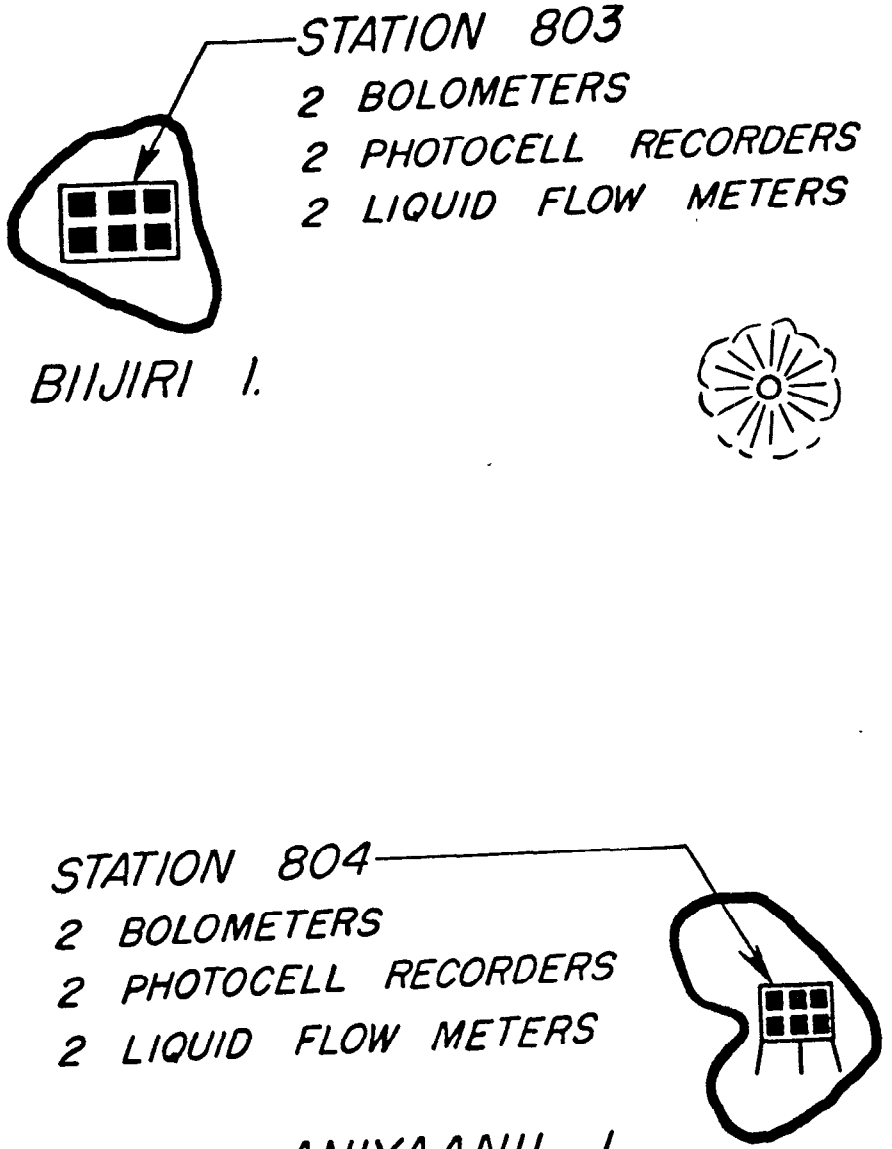


Fig. 8.2.1
Mike Shot Thermal Intensity as a Function of Time

8.2.4
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(not to scale)

Fig. 8.2.2

King Shot Thermal Intensity as a Function of Time

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PROGRAM 8

THERMAL RADIATION MEASUREMENTS

Project No: 8.3 Project Title: Spectroscopy

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. Harold S. Stewart
Address: Radiometry Section
Optics Division
Naval Research Laboratory
Washington 25, D. C.
Phone: Johnson 3-6600
EXT. 681

Conducting Agency: Radiometry Section
Optics Division
Naval Research Laboratory

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	4	M-45	K/10

Support Required:

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Object of the Experiment:

A complete documentation of thermal radiation as a "field variable" associated with exploding atomic bombs must include studies of the radiation energy spectrum. To the theoretician interested in weapon diagnosis, such information may explain an early phenomenon in the explosion development - or it may explain a connection between thermal radiation and another field variable, such as pressure. To the weapon effects theoretician, knowledge of a bomb's expected thermal spectrum will be an aid in predicting the penetrating power of the radiation - both through air and into more solid substances, such as human flesh.

This project is part of a continuing series of experiments, the purpose of which is to obtain as much information as possible concerning the thermal radiation spectrum associated with various sizes and types of atomic bombs - detonated under a variety of conditions. Both integral (summation over all time) and time dependent spectra will be measured. The relatively high yields expected from the IVY devices should insure a considerable extension of these data with respect to energy release.

Method and Procedure:

A. The classical method for measuring the energy spectrum of a radiation beam involves the use of an instrument known as a spectrograph. This instrument passes the beam through a "spreading" device (prism or diffraction grating) and then directs it to a photographic emulsion. The spreading device deflects each component of the incident composite beam by an amount dependent upon its energy. Hence the beam after spreading consists of a "fan" of smaller beams - each of the latter being essentially monoenergetic. These beams cause "exposure" in the silver halide of the emulsion - hence a dark line on the developed negative is associated with a particular energy level of electromagnetic radiation. The spectrograph record produced by a beam containing many different energies consists of many dark lines separated by lighter areas - the latter being associated with energy levels not represented in the beam.

Calibration of the instrument with known monoenergetic sources allows the experimenter to identify a given line on the record as being indicative of a given energy.

The above outlined technique does not, in itself, allow for time resolution. The record simply gives the integrated spectrum for whatever length of time the composite beam is incident upon the instrument. One way of obtaining the spectrum versus time is to add

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a shutter and moving film - then operating the spectrograph like a "motion picture" camera. A member of discrete integral spectra will thus be obtained, each covering a short period of time. The time resolution of such a system is fixed by the shutter and film speeds. Another way is to move only the film using no shutters. This technique supplies a continuous strip of spectrum (rather than a series of discrete spectra), each line of which is more or less dense as its length is traversed - depending upon the time variation of that particular energy.

For either of the above methods, timing marks are created on the film as it moves - in order that a particular spectrum can be identified with a given elapsed time from the start of the record.

B. For MIKE shot, moving film spectrographs will be installed at stations 800 on Engebi and 802 on Biijiri. At each of these stations measurements will be taken with two film speeds - one to obtain a spectrum every 2 milliseconds, the other to obtain a spectrum every 2 microseconds. The above mentioned "motion picture" technique will be used for the 2 ms resolution, whereas the continuous strip technique will be used for the 2 μs resolution. Each film frame of the slow speed record will contain 5 spectra. The first four of these are identical in content but with differing exposure levels, ranging from 1 to .03 on a relative scale, produced by the use of three ND* filters. The fifth is that of either a standard intensity source or a standard wave length source - whichever is most useful for calibration under the circumstances. The high time resolution will be produced by forming a 20 micron high spectrum of the source on a film moving at the rate of 25 meters per second. In this fashion, high time resolution is gained by sacrificing the range of intensities that can be covered.

In addition a high resolution of energies will be obtained on a integral spectrum. The instrument for this measurement will be installed in a small room directly below the photo tower cab on Parry island. Approximately 0.1 Angstrom (A)** wave length resolution will be obtained by using a 21 foot focal length 15,000 line grating in a Wadsworth mounting. The spectrum between 3800 and 8000 A will be formed on a plate 30 inches long, and simultaneously (by means of filter separation) the spectrum between 1900 and 4000 A will be formed adjacent to it. This folding technique, of course, effects a great saving in space.

For KING shot, the above mentioned Biijiri and Parry install-

* See the footnotes on page 3.5.2

** 1 Angstrom = 10^{-8} cm.

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ations will be activated. The measurements taken from them will be identical to those taken for MIKE shot.

Remarks:

The relatively poor energy resolution obtainable in the high speed spectra makes analysis of them very difficult. As a result, the high energy resolution of the records obtained with the integrating spectrograph serves as an analysis aid. For instance, a group of lines on the high speed record may look like a single blur, yet the position of this blur will allow it to be identified on the integral spectrum record. The energy resolution of the latter is sufficiently great that we no longer have a blur, but a group of well defined and distinct lines.

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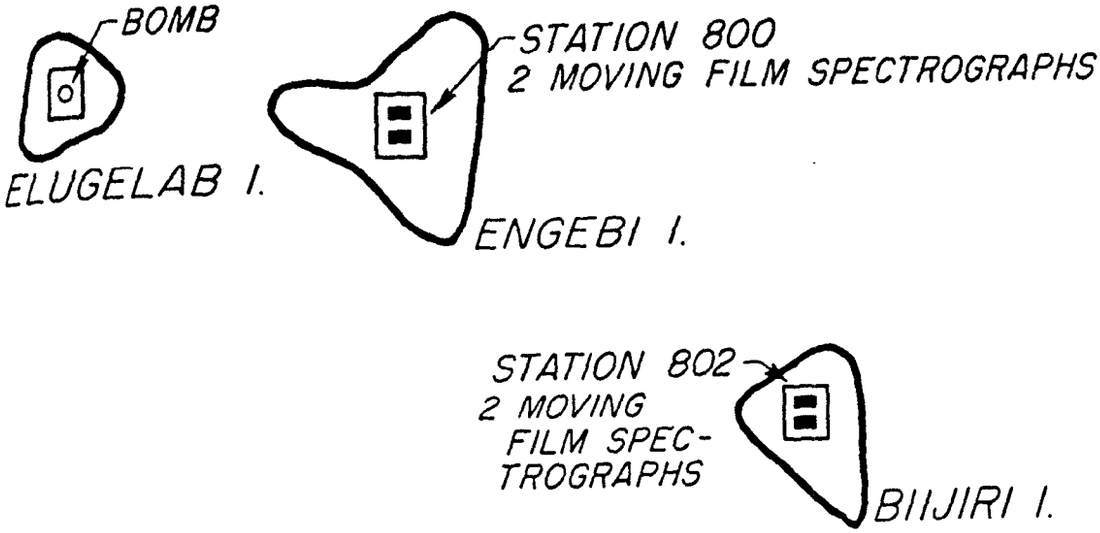


Fig. 8.3.1
Mike Shot Spectroscopy

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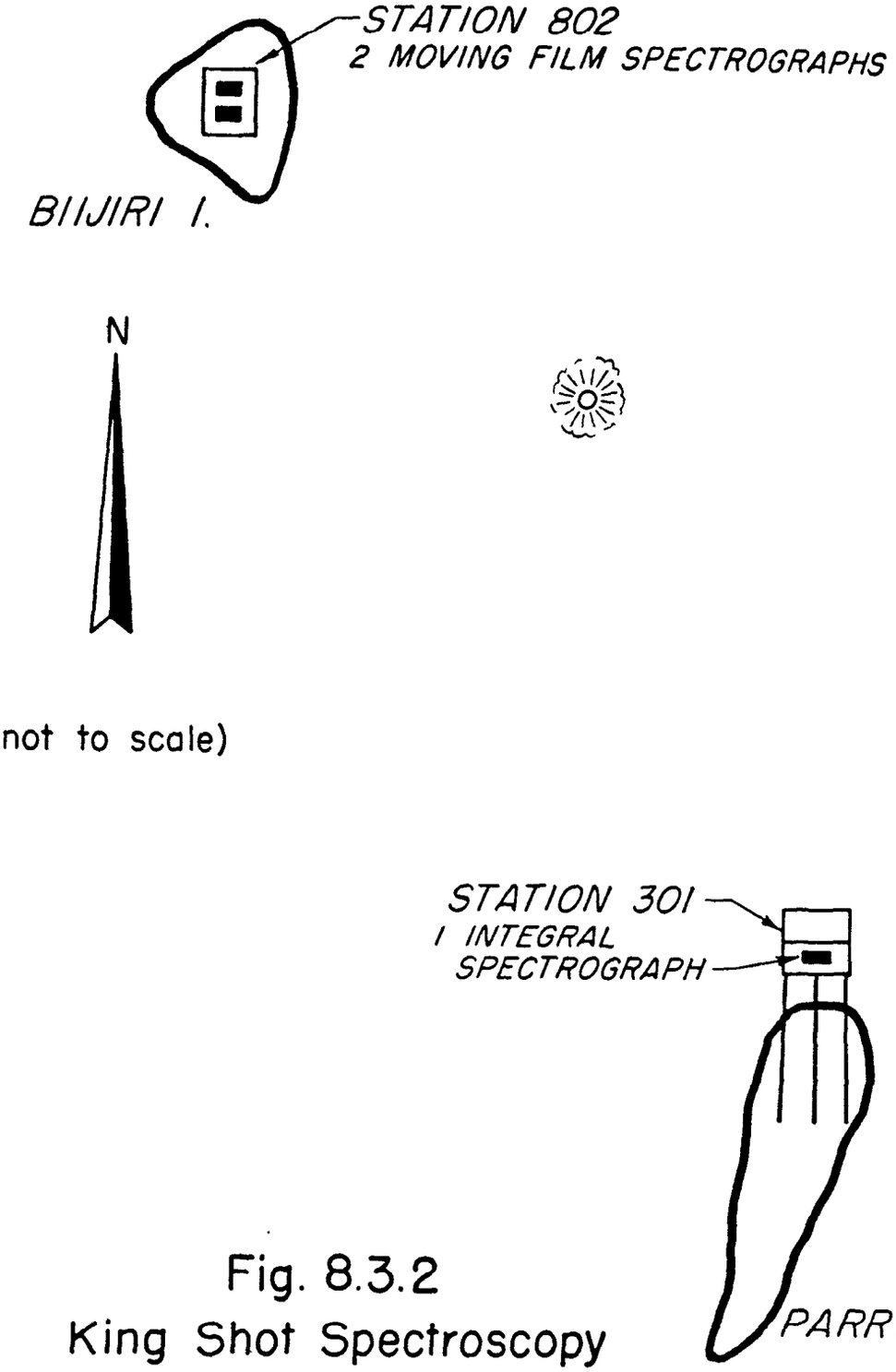


Fig. 8.3.2
King Shot Spectroscopy

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PROGRAM 8

THERMAL RADIATION MEASUREMENTS

Project No: 8.4 Project Title: Air Attenuation.

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. Harold S. Stewart
Address: Radiometry Section
Optics Division
Naval Research Laboratory
Washington 25, D. C.
Phone: Johnson 3-6600
EXT. 681

Conducting Agency: Radiometry Section
Optics Division
Naval Research Laboratory

Personnel Requirements in the Forward Area:

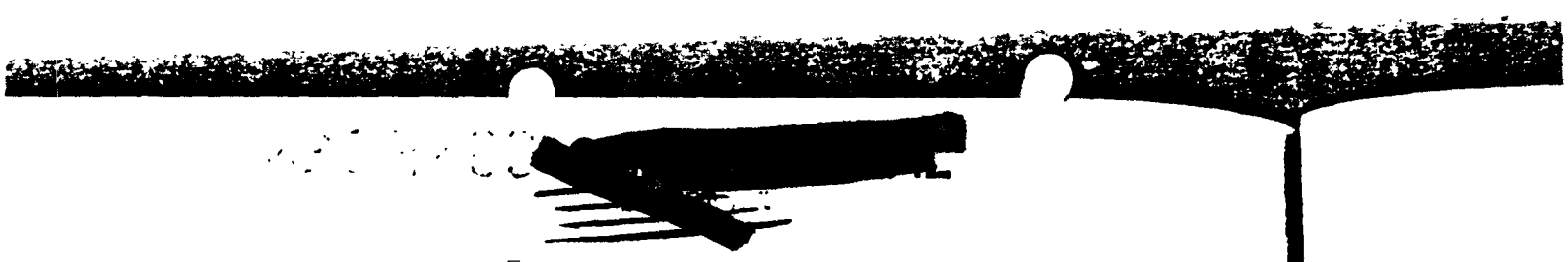
	Approximate Number	From	To
Officer	1	M-60	K+20
Enlisted			
Civilian	1	M-45	K+10

Support Required:

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Object of the Experiment:

In the discussion of Project 8.1, we considered an equation (equation 8.1.1) of great potential usefulness for the prediction of incident thermal radiation versus distance. The use of this equation for making predictions implies that one must know F as a function of yield and T (or λ) as a function of the atmospheric conditions. To obtain the latter functional relationships experimentally, we measure Q as a function of distance (see Project 8.1) and mathematically determine the values of F and T which allow the best "fit" of equation 8.1.1 to the observed data. The value of F thus obtained can be related to the measured yield of the weapon, to obtain another point on the F versus W curve. The documentation of T, however, is much more complicated, since the range of electromagnetic radiation in any medium is dependent upon the energy (wavelength) of the radiation as well as the characteristics of the medium. We therefore must obtain information as to:

(a) The energy distribution (spectrum) of the radiation emanating from an atomic weapon.

(b) The effective range of electromagnetic radiation in the atmosphere, as a function of energy and the atmosphere's ambient conditions.

The primary purpose of this project is to add to the already existent fund of knowledge for (b) above. The secondary purpose is to satisfy an operational requirement - this will be discussed under "Remarks" below.

Method and Procedure:

A. The observation of a known monochromatic light source enables one to obtain data as to the transmission of a particular wavelength in the electromagnetic spectrum over the path from the source to the receiver. Laboratory calibration of the source allows us to determine the actual wavelength and total energy being radiated. Similarly, laboratory calibration allows us to interpret the detector reaction as so much radiation energy received.

A typical known light source for field use consists of a parabolic reflector with a tungsten lamp mounted at its focus. The light from the projector is modulated at 60 cycles per second by a shutter mechanism to make it easier for the detector to distinguish between the primary light signal and "noise" created by scattered light from other sources. A typical receiver (detector) consists of a

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parabolic mirror with a photocell mounted at its focus. The current generated by the photocell is proportional to the intensity of light seen, and this current signal is used (usually after amplification) to actuate various types of recording devices.

B. Transmissometer (source, detector, and recorder) assemblies will be operated over several light paths at Eniwetok atoll for IVY.

For MIKE shot, one light source will consist of two 60 inch searchlights with 4000 watt tungsten lamps at their foci. One light will be used, and the other will be on automatic standby (the failure of the first will automatically turn on the second). The 60 cycle modulation will be produced by rotating a sector disc between the bulb and the mirror - 100% modulation being obtained. The searchlights will be mounted approximately 100 feet above sea level on the Parry photo tower, and the associated receiver will be on Elugelab - the latter consisting of a vacuum phototube mounted at the focus of a 60 inch (focal length) parabolic mirror, and its associated recording equipment. A similar set-up will be used between Bogon and Bogallua, with a smaller searchlight (18") source on Bogon. This pair of transmissometer assemblies will monitor the air attenuation along their lines of sight at all times prior to the shot, and they will be made a part of the "go-no-go" system in the firing circuit.

For KING shot, an attempt will be made to measure air attenuation between bomb zero and the thermal stations on Parry (photo tower), Aniyaanii, and Biijiri (station 803), until some few hours prior to the shot. A helicopter will be used, if possible, to hold the light source at the proper position.

Remarks:

For MIKE shot the success of Programs 2 and 3 is dependent upon good air transmission of light at shot time. This is considered to be sufficiently important to warrant a postponement of the shot if localized rain conditions cause the transmission to drop below prescribed values ($\sim 20\%$). Such a postponement, if necessary, will be made automatic by the following circuitry: When the current signal generated by the detector phototube (at either Elugelab or Bogallua) falls below the prescribed value, and stays below for 20 seconds, a relay will be opened. When it rises above the prescribed value, and stays above for 20 seconds, the relay will be opened again. The firing circuit is such that this relay must be open for the bomb to be detonated. The twenty second delay period is included so that a highly transient disturbance to the light path (such as a bird flying in front of the detector) will not actuate the relay.

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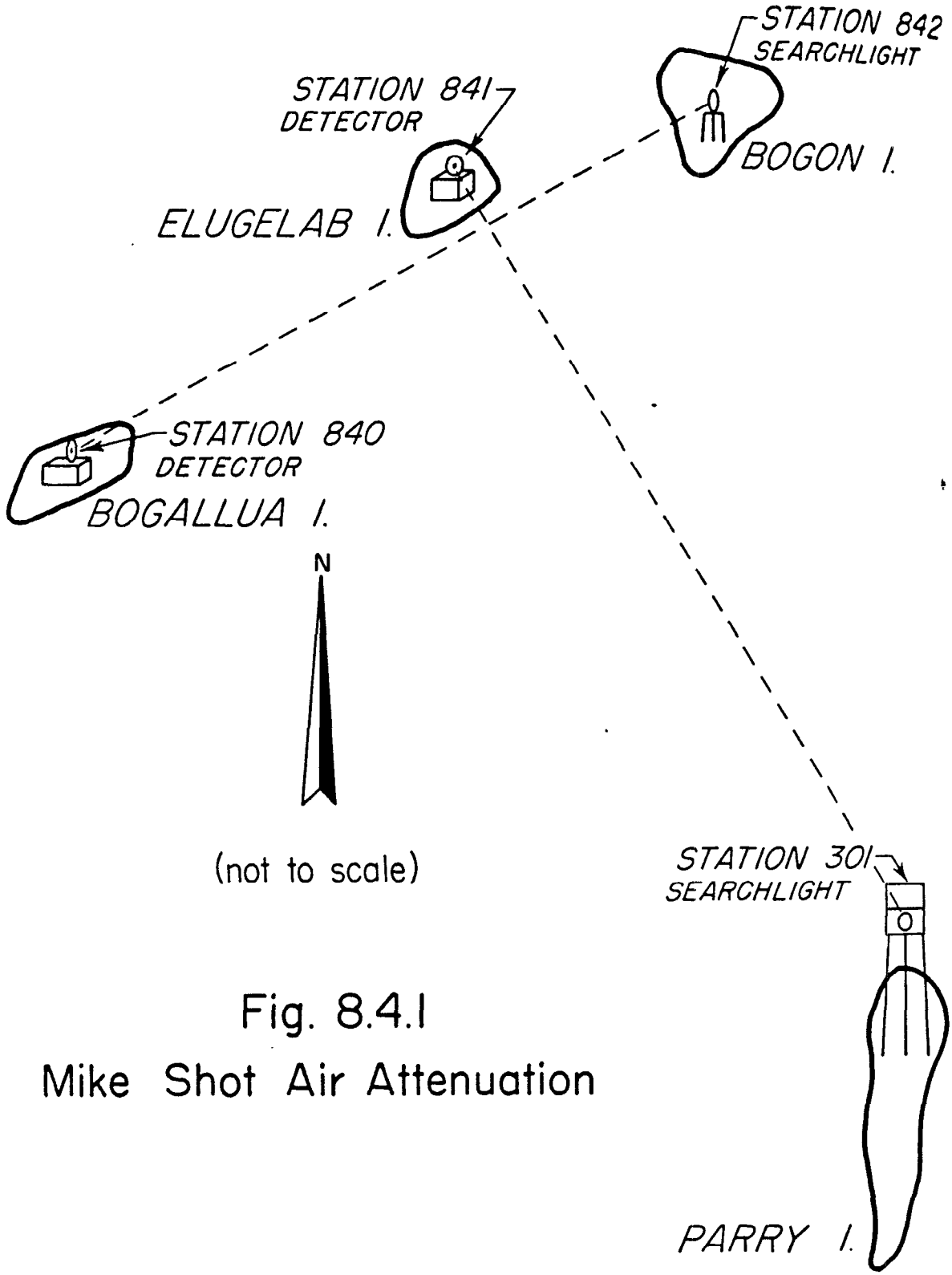


Fig. 8.4.1

Mike Shot Air Attenuation

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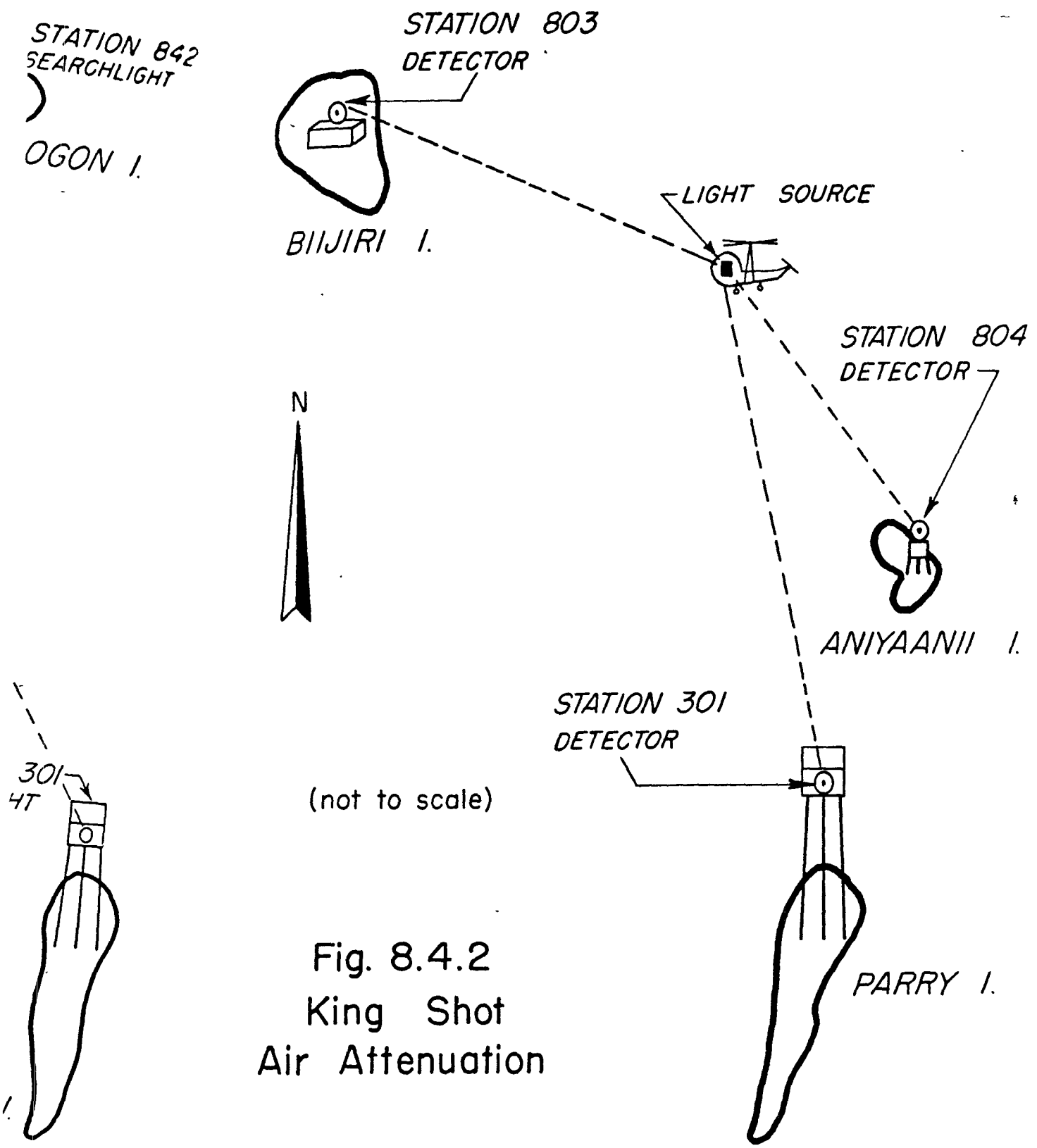


Fig. 8.4.2
King Shot
Air Attenuation

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PROGRAM 8

THERMAL RADIATION MEASUREMENTS

Project No: 8.5

Project Title: Thermal Radiation as a Function of Time in Free Air Utilizing Manned Aircraft.

Shot Participation: MIKE - KING

Sponsor: DOD (USAF)

Project Officer:

Name: Lt. Col. Rodney Nudenberg
Address: Wright Air Development Center
Wright-Patterson Air Force Base
Dayton, Ohio

Phone: Kenmore - 7111
EXT. 2-2226

Conducting Agency: Wright Air Development Center

Personnel Requirements in the Forward Area: *

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

(1) Utilization of the B-36D and the B-47B of Project 6.10.

(2) Use of one aircraft, preferably a B-29, for attenuation measurements and calibration; on a part-time basis only.

* Personnel for this project are reported under Project 6.10.

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Object of the Experiment:

This project is designed to determine, in free air at altitudes significant to delivery aircraft, the thermal radiation intensity as a function of time, and the maximum associated radiation-induced aircraft skin temperature. Such information is essential to studies of safe aircraft delivery procedures.

Method and Procedure:

The maximum skin temperature of the B-36D and B-47B aircraft of Project 6.10 will be determined with skin patches - located on the inside surface of the skin. Thermocouples, properly located for representative measurements, will also be used. The temperature as a function of time will be correlated directly with the thermal radiation intensity measurements made with a directed phototube.

Attenuation measurements will be made over a two week pre-shot period, using similar equipment in a B-29, to determine the air transmission properties under conditions as nearly similar to those existing at shot time as possible. A strong mercury-arc light source will be operated on or near Elugelab island three weeks prior to MIKE shot and attenuation measurements will be made on a number of days, at about the same hour of the day as proposed shot time. Such measurements will also be made immediately prior to the shot. It is also planned to have a similar light source on Runit island, and as many pre-shot attenuation measurements as possible will be made during the time interval between re-entry into the atoll subsequent to MIKE shot and KING shot.

At shot time the light source will be destroyed, but prior to this it will serve as a point for alignment of the phototube mentioned above.

Remarks:

The attenuation data obtained in Project 8.4 will be of great value in final analysis of the data obtained herein.

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Sponsor:

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PROGRAM 9

ELECTROMAGNETIC PHENOMENA

Project No: 9.1 Project Title: Electromagnetic Signals.

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Dr. Clyde L. Cowan
Address: P.O. Box 1663
Los Alamos, New Mexico

Phone: 2-2844
7-4000

Conducting Agency: Group J-12
Los Alamos Scientific Lab.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer			
Enlisted			
Civilian	1	M-35	K/1

Support Required:

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Object of the Experiment:

We have seen in other project discussions that electromagnetic radiation acts as an important energy transport mechanism for atomic explosions. Those projects, however, have been concerned with short wave length portions of the electromagnetic spectrum - heat, light, gamma radiation, etc. It also has been well established that a longer wave length component of the spectrum is radiated, but very little is known about the details of the phenomenon.

Past experimental results indicate that a broad-band radio signal of very high intensity is emanated by exploding fission bombs. The frequency range of the band extends from very low audio (one or two cycles per second) to moderately high radio (~100 megacycle) frequencies, and the total duration of the signal is approximately two seconds.

Naturally, one hopes to take advantage of such a phenomenon in some way. Perhaps it can be used in the field of long range detection, helping us to penetrate the atomic energy security mantle of another nation. Perhaps it can be used to supplant more cumbersome methods of diagnostic experimentation in our own weapon test programs. This experiment is part of a continuing effort to understand how, why, and where this radio signal is generated.

Method and Procedure:

A. The ordinary radio is designed to receive a very narrow band of frequencies at a given time - in order that the user may separate a desired signal from the host of those not desired. Such a "selectivity" is achieved by tuning the antenna system to resonate at a given frequency. Conversely, an untuned antenna (one with no resonant frequencies) is capable of detecting a wide range of radio frequencies simultaneously.

This experiment makes use of such an untuned antenna as its detector, and proceeds to amplify the signal in the normal "radio" fashion. The purpose here is not to drive a transducer, however, but to deflect the sweep of a cathode-ray tube. The amplified signal is fed simultaneously to the vertical deflection plates of several such tubes, each having a different elapsed time horizontal sweep (covering the range of 2 μs to 2 sec., approximately). A number of oscillographs are thus obtained (by photographing the tube faces for permanent records) of the induced signal, each accentuating a different detail.

B. Recording equipment will be operated at Parry island and at Los Alamos, for both MIKE and KING shots.

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PROGRAM 9

ELECTROMAGNETIC PHENOMENA

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ject No: 9.2

Project Title: Effects on the Ionosphere with Respect to the Propagation of Radio Waves.

t Participation: MIKE - KING

nsor: DOD (USA)

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ject Officer:

Name: Dr. C. M. Crenshaw
Address: Signal Corps Engineering Laboratories
Fort Monmouth, New Jersey

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Phone:

nducting Agency: U.S. Army Signal Corps

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	Approximate Number	From	To
Officer	2	M-30	K/10
Enlisted	4	M-30	K/10
Civilian	2	M-30	K/10

Support Required:

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(1) One transmission from an aircraft (WB-29, P2V, or PBM) operating 250 miles west of Eniwetok.

(2) LST-lift into Bikini atoll.

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Object of the Experiment:

This project is designed to determine the effect of an atomic explosion on the ionosphere, with respect to the propagation of radio waves.

Method and Procedure:

A. The effects of atomic explosions on oblique incidence radio signals reflected from the ionosphere and the attenuation caused by the ionosphere layers will, if practicable, be observed. A vertical incidence ionosphere height recorder will be located as near to ground zero as practicable to observe near effects. Other recorders will be located at suitable distances to observe the undisturbed ionosphere for control purposes.

Radio signals from various widely separated transmission paths will be recorded in an effort to determine unusual disturbances which may be correlated with previous projects and experiments. The effect of atomic explosion-induced ionospheric disturbances upon the scattering of radio waves will be observed. Serious disturbances of the ionosphere, with consequent interruption of routine radio communications, have been observed at past tests. This project is devoted to improving our understanding of the phenomena.

B. Several HF sky-wave circuits will be keyed preceding, during, and following the shot. Observations will be made relatively close-in (50-200 miles) to determine the effect of the explosion on the circuits monitored.

Vertical incidence CRPL Type C-3 automatic ionospheric-height recorders will be operated at Parry and Bikini islands. Special recordings will be made on C-3 recorders at existing Army Signal Corps and Department of Commerce ionosphere observation stations. Back-scratcher ionosphere equipment will be operated to sweep the ionosphere azimuth-wise. Field intensity measurements will be made at Guam of WWVH transmissions from Maui, T.H., prior to and during the test.

A simulated practical communications system will be operated as follows:

(a) Transmit on about 3 megacycles at Eniwetok using an antenna with maximum radiation in an upward direction. The transmission will use radio teletype keying and will be on test tape. It will be observed, on a con-

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uous basis, at Bikini and other mobile stations in the shot area.

(b) Transmissions will be made in the high frequency band from aircraft 250 miles west of Eniwetok, diametrically opposite Bikini. These will be observed at Bikini and other designated stations.

Observations will be made on long wavelength radio communication circuits originating at Guam, Honolulu, and other locations.

Remarks:

This project will be closely coordinated with Projects 7.1 and 9.3.

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PROGRAM 9

ELECTROMAGNETIC PHENOMENA

ject No: 9.3

Project Title: Investigation of Electromagnetic Radiation Throughout the Radio Spectrum Caused by an Atomic Explosion.

Participation: MIKE - KING

nsor: DOD (USA)

ject Officer:

ame: Mr. Peter Brown
ddress: Commanding Officer
Evans Signal Laboratory
Belmar, New Jersey

hone:

ucting Agency: U.S. Army Signal Corps

rsonnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-30	K/10
Enlisted	4	M-30	K/10
Civilian	2	M-30	K/10

pport Required:

(1) Firing alert for remote stations.

(2) Timing signals for Runit and Parry island stations.

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Object of the Experiment:

This project will attempt further quantitative investigations of the electromagnetic pulse caused by atomic explosions, recording sufficient data, over a wide band of search frequencies, to support a theoretical study of the phenomenon.

Method and Procedure:

A. Special close-in measurements of the radiated pulse spectrum will be made. In addition, radio receivers and recording apparatus will be employed at various distances to record evidence of the phenomenon, to determine field strength and establish the frequency distribution. Current investigations have been initiated to determine the validity of the phenomenon on theoretical grounds.

B. A spectrum analysis of the radiated pulse will be made on Runit and Parry islands. Observations will be made at Hawaii and Belmar, New Jersey, on 10 kilocycles (using sferics receivers). Observations will also be made at such stations as Adak, Okinawa, Bikini, Kwajalein, Guam, Japan, and Belmar, New Jersey, guarding optimum propagation frequencies.

Remarks:

This project will be coordinated with Projects 7.1 and 9.2. The data obtained herein will be complimentary to that obtained from the radar scope photography in Project 9.4, and each will aid in the analysis and interpretation of the other as techniques for indirect high yield weapon detection.

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PROGRAM 9

ELECTROMAGNETIC PHENOMENA

Project No: 9.4

Project Title: Evaluation of Indirect Bomb Damage Assessment Techniques.

Joint Participation: MIKE - KING

Sponsor: DOD (USAF)

Project Officer:

Name: Lt. Col. Rodney Mudenberg
Address: Wright Air Development Center
Wright-Patterson Air Force Base
Dayton, Ohio

Phone: Kenmore 7111
EXT. 2-2226

Conducting Agency: Wright Air Development Center

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-30	K+5
Enlisted	5	M-30	K+5
Civilian	2	M-30	K+5

Support Required:

(1) Utilization of Project 6.10 aircraft, as well as any other aircraft within sufficient range and with adequate airborne radar equipment.

(2) Four Bhangmeters - to be supplied by EG&G.

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Object of the Experiment:

It is planned herein to evaluate components of the IEDA which is installed in aircraft scheduled to participate in Projects 6.10 and 8.5.

Method and Procedure:

A. Photographs of radar scopes will be made during the atomic explosions, and a detailed analysis will be made of the value of this technique as a measure of bombing accuracy, bomb damage, and weapon yield.

B. The basic radar equipment of the B-36D, the B-47B, and any available B-50's and B-29's will be utilized. These equipments are either complete AN/APQ-24 radar systems or APS-23 radar sets, the former incorporating the latter as part of the system. The response of the radar sets to each detonation will be observed and photographed on 35 mm film using standard O-15A camers (~15 frames/sec).

Indications of actual burst height and circular bombing error are to be obtained from the PPI presentations. In order that yield estimates can be obtained shortly after detonation (for correlation purposes), four Bhangmeters will be carried - two in each aircraft. The latter are described under Project 3.6.

Remarks:

1. Any radar sets and cameras equivalent to the above mentioned types that are airborne and within 50 to 75 miles from Eniwetok should be turned on and film should be made available to and later collected from each.

2. This project is a continuation of similar test projects conducted at GREENHOUSE, BUSTER-JANGLE, and TUMBLER-SNAPPER. Radar scope data is also available from CROSSROADS, SANDSTONE, AND RANGER. It is proposed that all these data be compiled and be the basis for a continuing Air Force study of this indirect bomb damage assessment method.

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PROGRAM 10

TIMING AND FIRING

Project No: 10.1 Project Title: Timing and Firing.

Shot Participation: MIKE - KING

Sponsor: AEC

Project Officer:

Name: Mr. Herbert E. Grier
Address: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Mass.

Phone: Copley 7-3520 (Office)
Bigelow 4-4956 (Home)

Conducting Agency: Edgerton, Germeshausen & Grier, Inc.
160 Brookline Avenue
Boston 15, Massachusetts

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer	3	M-42	K/7
Enlisted			
Civilian	1	M-42	M/10

Support Required:

* Plus seven additional civilians from M-42 to K/7.

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Object of the Experiment:

This project is responsible for supplying all timing signals required by the IVY experimental program, and for supplying the firing pulse to the detonators of the MIKE shot weapon. Having such responsibilities, its most serious problem is that of maximizing the reliability of its equipment - a most perplexing problem indeed when one considers that Eniwetok atoll must be completely devoid of personnel for MIKE shot.

The importance of reliable timing signals for a complex experimental program of this type seems obvious. In fact, no exaggeration is involved in the statement that the success or failure of many experimental projects is heavily dependent upon their receipt of accurate and dependable pre-shot timing signals. Most measuring devices need to "get ready" just before they take a measurement - and many such devices need stopping before they try to measure too much. Timing signals are used to solve such problems.

Method and Procedure:

A. Consider an imaginary experiment station, S, which contains an assembly of experimental equipment, E. E is to be used for some measurement during an atomic explosion, and its proper operation depends upon the following sequence of events:

(a) 30 minutes prior to zero time an electric motor must be started.

(b) 5 minutes prior to zero time a voltage must be applied to the plates of a condenser.

(c) 1 minute prior to zero time the protective cover of a lens must be raised.

(d) 1 second prior to zero a shutter must be opened.

(e) At zero time the condenser must be discharged.

(f) 1 second after zero the shutter must be closed, the protective cover lowered, the voltage removed from the condenser plates, and the motor stopped.

The experimenter builds E in such a way that the closing of a switch is sufficient to cause each of the above to take place. He

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...then supplied with five relays (by those responsible for timing) ...h can be installed in S. The relays furnish the above mentioned ...ches for E, a separate relay being used for each circuit which re... its switch to be closed at a different time. Signal wires ex... from each relay to the nearest distribution station of the timing ...tem - which serves a number of experimental stations in addition ...S.

Each distribution station contains one relay for each time ...al available in the system - the closing of which actuates every ...perimental station relay intended to be closed at that time. Signal ...es extend from each distribution station relay to a corresponding ...tch in the central timing station. The latter is arranged to be ...rated either by hand or by a mechanically driven cam.

As an example, then, the sequence of events at 1 second prior ...zero is:

(a) The 1 second switch in the central timing station is closed - by a motor driven cam in this instance. This allows a signal to pass along the 1 second "line" to all distribution stations, where

(b) All 1 second distribution station relays close. This allows current to flow in the 1 second lines leading to experimental stations, where

(c) All 1 second experimental station relays close. This is the final desired result, and, in the case of E above, the shutter will open.

The above outline is perhaps over-simplified, but it will ...rve to identify the components in the IVY description which follows.

B. The timing signals which past experience has shown will meet ...e requirements of most experimenters are as follows:

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(a) For a tower shot

Type	Time (with respect to zero	Error (with respect to actual zero)	Remarks
Manually operated	-60 min	0.5 sec	
"	-30 min	"	
Automatic (cam operated)	-15 min	0.1 sec	
"	- 5 min	"	
"	- 1 min	"	
"	-30 sec	.05 sec	
"	-15 sec	"	
"	- 5 sec	"	
"	- 1 sec	"	
"	ZERO	"	For "Dry Runs" only
"	∕ 1 sec	"	Cut-off for all relays

(b) For an air burst

Type	Time	Error (with respect to predicted zero)	Remarks
Manual	-15 min	See "Remarks"	
"	- 5 min	"	
Automatic	-30 sec	0.05 sec	
"	-15 sec	"	
"	- 5 sec	"	
"	- 2.5 sec	"	

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(b) For an air burst (Continued)

Type	Time	Error (with respect to predicted zero)	Remarks
Automatic	- 1.5 sec	0.05 sec	
"	- 0.5 sec	"	
"	ZERO	"	For "Dry Runs" only
"	+ 3 sec	"	Cut-off for all relays

Two of the master switches are actuated by manual push buttons, and the remainder by an automatic sequence timer. The automatic sequence timer (or cam sequence timer) is a precision device driven by a synchronous motor. The timing cams operate mercury master switches in the proper sequence. For a tower shot, a sequence-start button (manually operated) places the cam timer in operation, and the timer shuts itself off after opening all the signal circuits after zero. For an air drop, a radio tone signal is interrupted at the time of bomb release, and controls the actual start of the cam timer.

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relays

Power to actuate all relays is supplied by batteries. In every case, the batteries are located in the station from which the signal comes - that is, the power to actuate the experimental station relays is provided by batteries located in the associated distribution station, etc.

All relays are type DN-11 railroad relays, which can operate on as low as 7.5 or as high as 100 volts. The operating time is essentially constant for voltages across the coil in excess of 25 volts. Four double-throw switches are available on each relay for the experimenters use. Two of these switches are rated at 10 amperes, and the remaining two are rated at 4 amperes.

Each relay circuit contains a monitoring milliammeter, in order that faulty operation of the circuit may be diagnosed. The criteria for meter location are identical with those mentioned above for battery location.

The fundamental limitation on the total number of basic time signals is the availability of lines from the control station. Since it is not feasible to string several miles of line for one additional time, the practice is for an experimenter to receive a standard signal and construct a delay line which will adapt it to his individual needs.

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For an air drop, uncertainties in the release time and time-of-fall force all signals to be given with respect to predicted zero - and actual zero may vary from predicted zero by as much as 1.5 seconds either way. Thus no signal can be expected to exhibit an accuracy with respect to actual zero of better than ± 1.5 seconds. Signals given prior to release time (for example, a -15 minute signal) must obviously be given without knowledge of what the actual precise release time will be. It is quite possible for conditions on the ground or in the plane to delay, or cause an abort of, the planned bomb run. Approximately 25 minutes are required for the plane to make another run - hence such an eventuality will delay zero time by that amount. The practical significance of this is that batteries (for instance, a filament supply) that are turned on prior to expected release time should be capable of supplying current for the time necessary to make one or two extra bomb runs.

For pre-shot test purposes in the field, a practice (or "dry") timing signal run is made twice each day - with zero times at 1000 and 1500 hours local time. An experimenter receives any or all of these "dry run" signals, by his request only. Reliability considerations, of course, dictate his use of a maximum number of dry run signals.

C. In addition to the above system, "Blue Boxes" are available to those experimenters requiring them. The Blue Box is a device which responds to a very fast-rising (in intensity) light signal - and hence to the initial bomb light but not to extraneous sources. Its response consists of suppling either or both of two signals. The first of these is a voltage pulse rising to ~200 volts within 100 μs after zero, and holding at ~100 volts until manually reset. The second is a relay closure which is completed within 2 ms after zero. The relay includes one double throw switch, the contacts of which are rated at 2 amperes. The Blue Box is self-contained and weather proof. Models are available for both standard (110 volt) AC power line and battery operation.

D. Everything we have said thus far applies to timing systems in general, and only one restriction has been implied - the existence of a man at the central timing (control) station to actuate the manually operated switches. For MIKE shot, this restriction cannot be satisfied since the atoll will be completely evacuated - hence an additional link will be required in the system. The link will be supplied by radio control, and television monitoring, of the Elugelab central timing station from the "Estes" in the evacuation fleet. For details of the radio link operation, the reader is referred to the Project Officer.

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E. The possibility always exists that experimental conditions will be such that a shot must be stopped and delayed. For air drops, radio contact is maintained between the control station and the dropping aircraft - and a verbal order to the bombardier can prevent release of the bomb if given early enough. For surface shots, a master disconnect switch is included in the system to allow manual stoppage after the sequence timer is actuated.

In addition, for surface shots, one wishes to allow for the necessity of a shot stoppage that can not (or need not) be subjected to the vicissitudes of human reaction. Two examples suggest themselves:

(a) If something untoward happens less than a second before zero, it may well be too late for a human to find out about it - or to decide what to do if he does find out - or pull the switch if he decides.

(b) Certain eventualities are so serious that their occurrence does not require a last-minute decision. If they do occur, the shot must be stopped.

One solution to the problem implied by these examples is the inclusion of one or more automatic master disconnect switches in the firing circuit. Such a system bears the name "go-no go", and will be included for MIKE shot. The discussion of Project 8.4 describes one of the go-no go installations. Another will be supplied by the cryogenics system.

F. Firing signals originate in the control station in the same manner as the cam timing signals, a separate "zero" cam being used. The master disconnect switch, and the remainder of the firing circuit, is isolated from the timing system for safety's sake.

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PROGRAM 10

Project No: 10.2 Project Title: Release Tone.

Shot Participation: KING

Sponsor: AEC

Project Officer:

Name: Mr. C. B. McCampbell
Address: (Code 5225-1) Sandia Corporation
Sandia Base, Albuquerque, New Mexico

Phone: Albuquerque 6-4411
EXT. 2-3215

Conducting Agency: Weapons Performance Division
Sandia Corporation

Personnel Requirements in the Forward Area:*

	Approximate Number	From	To
Officer			
Enlisted			
Civilian			

Support Required:

* The personnel requirements of this project are included in those of Project 2.5.

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Object of the Experiment:

In the discussion of Project 10.1, we mentioned the use of a cam-driven sequence timer to actuate the majority of the timing signal master switches. We also mentioned that, for an air drop, the sequence timer is triggered (started) by the interruption of a radio tone signal when the bomb is released. This project is responsible for furnishing the starting signal to E.G.&G.'s sequence timer - in order that the complex timing-signal system described previously may be put into operation. Reliability is the most important boundary condition (to the design and operating techniques used herein) implied by such a responsibility.

Method and Procedure:

A. Knowledge of the objective to be achieved by this experimental project makes the basic method of achievement obvious. Prior to the release of the bomb, a radio tone signal is transmitted from the dropping aircraft. When the bomb leaves its shackle, this signal is interrupted. The line which supplies power to the sequence timer contains a relay-actuated switch, the relay coil being connected to a radio receiver which is tuned to detect the tone signal. As long as the tone signal is being transmitted, the switch is held open; the interruption of the tone, however, allows the switch to close. The latter starts the sequence timer and "the die is cast". The equipment duplication techniques, used to augment this basic method (see below), are indicative of the striving for reliability.

B. Two transmitters (transmitting on different frequencies) will be operated in the dropping aircraft, a normally-closed switch being located in the "ground" line of each (S_1 and S_2). These switches are opened (by remote control, utilizing sealed micro-switches) when the bomb is released. Two relay-actuated normally-open switches (in series) are located in the sequence timer power line (S_3 and S_4), - each relay coil being connected to an associated receiver. Each receiver is tuned to the frequency of one airborne transmitter.

The opening of S_1 and S_2 interrupts both tone transmissions. This in turn causes the receivers to pulse their respective relay coils, closing S_3 and S_4 - which allows current to flow to the sequence timer. The series connection of S_3 and S_4 implies that both tone signals must be interrupted before the sequence timer can start - hence the failure of one transmitter or one receiver cannot cause the timer to be actuated prematurely.

The above is a highly simplified representation of the equip-

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ment used by this project. The reader interested in a more detailed exposition is referred to the Project Officer.

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PROGRAM 11

PRELIMINARY GEOPHYSICAL SURVEY OF THE TEST AREA

Project No: 11.1

Project Title: Soundings of the Ocean Side of Eniwetok Reef.

Shot Participation: Pre-Shot

Sponsor: DOD (AFSWP & ONR)

Project Officer:

Name: J. W. Smith
Address: Office of Naval Research
Washington 25, D. C.

Phone: Liberty 5-6700
EXT. 6-4476

Conducting Agency: Hydrographic Office
U.S. Navy Department
Washington 25, D. C.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	4	M-150	M-120
Enlisted	60	M-150	M-120
Civilian	3	M-150	M-120

Support Required:

(1) Placement of targets on islands for surveying ship location.

(2) Use of photographic facilities ashore.

(3) Minor use of laboratory and shop facilities ashore.

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Object of the Experiment:

Although many water depth soundings have been made in Eniwetok lagoon and in the deep ocean water outside the island ring, the configuration of the close-in oceanside profile of the reef is unknown. Because of the expected magnitude of MIKE shot, there is some possibility that the reef may be shattered and breached in the vicinity of the shot island. It is therefore important that the reef configuration be determined before the shot. Such soundings will also provide information necessary for possible model studies of the atoll, to aid in the interpretation of shot-time measurements.

Method and Procedure:

The Navy Hydrographic Office has agreed to make the necessary soundings. The method employed will be a modified acoustic sounding system, whereby a vertical "fan" of acoustic pulses will be directed against the ocean side of the reef, the echoes being recorded by photography of oscillograph traces. The work will be done from the COCOPA (ATF-101), supported by a 42-foot boat for close-in measurements. Detailed sounding profiles, to a depth of several hundred fathoms, will be taken at 500-yard intervals for a distance of five miles either way from Elugelab and at intervals of about one mile for the remainder of the reef perimeter. This work will be accomplished during June, 1952.

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PROGRAM 11

PRELIMINARY GEOPHYSICAL SURVEY OF THE TEST AREA

Project No: 11.2 Project Title: Scaled Ground Shock Tests.

Shot Participation: Pre-Shot

Sponsor: DOD (AFSWP)

Project Officer:

Name: H. K. Stephenson
Address: P. O. Box 1663
Los Alamos, New Mexico

Phone: 2-4380

Conducting Agency: Los Alamos Scientific Lab.

U. S. Coast and Geodetic Survey
Washington 25, D. C.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	1	M-225	M-195
Enlisted			
Civilian	3	M-225	M-195

Support Required:

(1) Two seismic stations on San Ildefonso (Sta.11) and Rigili (Sta.13).

(2) Logistic support within the atoll.

(3) Occasional use of heavy equipment such as tractors, bulldozers, trailers.

(4) Support from Task Group 132.2 consisting of 15-man team (to handle high explosives) and approximately 10 radio operators.

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Object of the Experiment:

Predictions as to the ground shock at any given distance from an explosion may be based on scaling laws, which have in turn been based either on theoretical assumptions or on actual measurements for a series of shots of different yields. For a particular geological setting measurements in situ must be made. It was therefore decided to make a series of ground shock measurements at Eniwetok. Such measurements can serve as a check on predicted scaling laws and also as a measure of ground shock attenuation under the particular sub-surface conditions at the atoll.

Method and Procedure:

A series of scaled shots for ground shock measurement were made at Eniwetok during March and April, 1952. The high explosive charges for these consisted of a combination of Composition C-2 and Tetrytol. Five shots were fired, these being the equivalent of 1, 5, 10, 15 and 20 tons of TNT.

The shots were arranged in a "beehive" configuration, the base of which was placed at the saturated sand level on the shoreline of Elugelab near proposed MIKE zero point. Motion pictures of each shot were taken, for a study of wave action.

Seismic recordings for ground shock measurements were made at five stations around the atoll, with seismographs provided by the U. S. Coast and Geodetic Survey. These stations were at San Ildefonso (1200 yards), Engebi (6000 yards), Runit (25,100 yards), Rigili (27,800 yards), and Eniwetok (41,700 yards).

The records of both the seismic and photographic measurements are being analyzed at the present time.

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PROGRAM 11

PRELIMINARY GEOPHYSICAL SURVEY OF THE TEST AREA

Project No: 11.3

Project Title: Deep Drilling to Base Rocks.

Shot Participation: Pre-Shot

Sponsor: DOD (AFSWP & ONR)

Project Officer:

Name: Gordon Lill
Address: Office of Naval Research
Washington 25, D. C.

Phone: Liberty 5-6700
EXT. 6-2346

Conducting Agency: Drilling and Exploration Company,
Abilene, Texas

U. S. Geological Survey
Washington, D. C.

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	2	M-165	M-135
Enlisted	12	M-165	M-135
Civilian	20	M-180	M-120

Support Required:

(1) Heavy equipment for moving drilling rig, drill pipe, casing, etc. to first location (Sta. 1130, Elugelab), second location (Sta.113 Site Mack), and aboard ship.

(2) Support by 14-man Seabee team to build drilling platform of Navy T-6 pontoons on Site Mack. Heavy equipment support and some labor help for this team from Holmes and Narver.

(3) Military aid for handling and firing explosives to prepare Site Mack.

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Object of the Experiment:

Although coral atolls have been studied in one way or another for many years, much is still unknown about their structure. From various indirect evidence it is assumed that the rings of coral islands are built on eroded flat-topped platforms of volcanic origin and basaltic composition. The validity of this assumption has never been checked by drilling through the coral to the basement structure beneath.

Drill holes at selected locations on the atoll will give direct information on the geologic column which cannot be obtained in any other way. Deep drilling will give a direct measure of the depth of coral as well as determining the proportion of sand and rock layers. It will provide information necessary in the interpretation of the seismic refraction survey (Project 11.4) and will give an opportunity for determining vertical seismic profiles by velocity shooting.

Method and Procedure:

A deep-well rotary drill rig of the type used for oil wells will be used to drill two holes, each to an estimated depth of 5000 feet - or into the unaltered basement rock. Continuous samples of the drill cuttings will be taken, and at intervals cores of the rock will be cut for study.

The first drill hole will be near the shot point on Elugelab in order to determine subsurface conditions there before the disturbance created by the shot. The second hole will be drilled from a Navy steel pontoon platform on the shallow coral head (Site Mack) in the lagoon west of Runit. This second hole will provide information on subsurface conditions near the middle of the atoll structure and will be especially valuable in the interpretation of the seismic refraction survey.

It is expected that the drilling will be completed by early July, 1952.

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PROGRAM 11

PRELIMINARY GEOPHYSICAL SURVEY OF THE TEST AREA

Project No: 11.4 Project Title: Seismic Refraction Survey.

Shot Participation: Pre-Shot

Sponsor: DOD (AFSWP & ONR)

Project Officer:

Name: J. W. Smith
Address: Office of Naval Research
Washington 25, D. C.

Phone: Liberty 5-6700
EXT. 6-4476

Conducting Agency: Scripps Institution of Oceanography
La Jolla, California

Personnel Requirements in the Forward Area:

	Approximate Number	From	To
Officer	8	M-30	M-1
Enlisted	120	M-30	M-1
Civilian	25	M-30	M-1

Support Required: Erection of high targets for positioning ships up to 20 miles offshore.

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Object of the Experiment:

In order properly to interpret seismic measurement made in conjunction with high yield weapon tests, the seismic characteristics of the substructure in the region around the shot should be known. Measurements of these characteristics can be made by conducting a seismic refraction survey, of the same type as is used so widely in exploration for oil. In such a survey high explosive charges are fired at one point and the resulting refracted elastic wave is detected by a recorder at a second point. By varying the spacing between shots and recorder, the results can be interpreted in terms of the elastic constants and structure of the underlying rock layers.

Such a survey was recently completed at Bikini by an expedition from the Scripps Institution of Oceanography, and yielded much information indicating a rather complex structure under the atoll. The proposed survey at Eniwetok should yield more significant information because of the additional control provided by the deep-drill holes and experience gained during the Bikini survey.

Method and Procedure:

The refraction survey will be based on the technique worked out at Bikini, and the same group which conducted the Bikini survey will work at Eniwetok.

Two ships will be used, one for firing explosive charges, the second to act as recording point for the seismic waves. Detection of the waves will be by means of a hydrophone trailed behind the recording ship. In such a technique the water is considered as one layer of a multi-layer problem. Furthermore, the known seismic velocity for sea water is used to measure the separation of the two ships.

Measurements will be made along traverses criss-crossing the lagoon, and these will be interpreted in terms of the configuration of the subsurface layers under the atoll. The two deep-drill holes will give positive control for the interpretation of measurements.

Field work for the seismic refraction survey will be completed during the month preceding MIKE shot.

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[redacted]

1950 Plans for the use of X rays to compress T + D capsule in forthcoming 1951 Greenhouse-George nuclear weapon test at Eniwetok

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ADWD-146

FAMILY COMMITTEE
Minutes of Twelfth Meeting
June 1, 1950

A. Attendance.

The twelfth meeting of the Family Committee was held Thursday, June 1, 1950 at 1:15 in Room B-117. Since the items on the agenda were not finished during this session, the Committee appointed a substantial subcommittee to continue in session throughout Friday, June 2 and Saturday morning, June 3. The entire Committee reassembled on Saturday, June 3 at 1:15 P.M. in Room B-117. The report rendered below is a composite of these sessions without regard to chronological order. Those present during the sessions were:

H. M. Agnew	J. M. Keller
H. V. Argo	E. Konopinski
N. E. Bradbury	D. P. MacDougall
H. Bradner	J. C. Mark
J. C. Clark	W. E. Ogle
F. de Hoffmann	F. Reines
D. K. Froman	L. B. Seely
R. W. Goranson	B. R. Suydam
A. C. Graves	R. F. Taschek
E. F. Hammel	E. Teller, Chairman
M. G. Holloway	J. A. Wheeler
E. R. Jette	H. F. York

B. Minutes of the Eleventh Meeting.

The Committee unanimously adopted the minutes of the Eleventh Meeting reported in ADWD-141, with the following corrections:

(1) On page 4, the third line from the bottom, the new sentence should start: "A time $\tau/2$....."

(2) On page 6, line 11, change the figure 60' to read 60".

C. General Problems Concerning X-ray Experiments.

Graves opened the discussion by presenting the Committee with a series of questions which had to be answered in the near future in order to proceed with the planning of the X-ray experiment. These questions were the following:

1. What spots are to be measured.

2. What quantities are to be measured and with what precision.
   (a) Is the radiation black body? i.e., what frequencies must we measure?
   (b) Time and temperature range for each spot.

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3. Interpretation of data.

(a) Is there a pip in x-rays?

(b) [redacted]

(c) [redacted]

Bearing these typical questions in mind, the group proceeded to a discussion of separate items involved in the X-ray experiment. In the course of these, the above questions were answered in Sections D through F below; except for question 3(b).

[redacted] Rather, any results will be more in the nature of supporting arguments in answering such a question.

DOE b(3)

[redacted]

DOE b(3)

[redacted]

(γ) Deviations of the temperature distribution from a black body spectrum.

(δ) Information concerning the high-energy x-rays emanating from the DT mixture when it goes.

D.

DOE b(3)

The problem that was considered was the radiation distribution in a slab of thickness S where the temperature at the inner surface is denoted by T_o and the temperature at the outer surface is denoted by T_s.

DOE b(3)

The other curve on Figure 1 shows the results of an equilibrium calculation.

DOE b(3)

It will be noted that this curve does not differ radically from the one for the first radiation breakthrough.

DOE b(3)

It should be noted that all the above calculations and formulas 1 and 2 are based on analytical fittings for the opacity data. These formulas have less accuracy than one can eventually hope for in these relations if one uses numerical integrations from the actual calculated opacity points that are now known.

[redacted]

It would, however, be desirable to have a "transparent spot" somewhere in the wall. Such a spot, which would be more transparent than the wall itself, would have the advantage that radiation would break through at an earlier stage. Thus, one could observe phenomena at an earlier time and moreover the original temperature distribution is not likely to be so distorted as that which comes through the main part of the wall at a slower rate. We shall return at a later time to a further discussion of one or more transparent spots.

[redacted]

It was agreed to refer this problem to a committee consisting of Konopinski, MacDougall and Taub, and to request them to report to the Family Committee what solution they have adopted.

[redacted]

DII. Number, Type and Location of Spots.

Teller reminded the Committee of the dual function of the X-ray experiment, to serve as

a. A diagnostic experiment.

[redacted]

b. An engineering experiment.

[redacted]

Point of view b should not be sold short. Taschek remarked that, on the other hand, point of view a would gain added weight if the experiment should turn out to be a failure and the DT would not go. As a matter of

[redacted]

Hence a second scope has been added so that there is some possibility of detecting this distortion.

[redacted]

Because of the experimental difficulties involved, no detecting method chosen is likely to be fool-proof. Thus it would be advisable to have two parallel detecting methods employed (the particular ones favored at present are described in Section F below). Hence in order to buy this amount of insurance we must essentially double the number of detectors and scopes. Thus the total number of detectors is 10 and the total number of scopes 16. To this we must add three scopes for intercalibration of timing and one scope for a timing tie-in with other experiments such as DINEX. In addition, it would be valuable to run a blank detector and ~~blank scope so that we finally end up with the following numbers:~~ [redacted]

2. Transparent spot looking at DT. Such a transparent spot would yield diagnostic information directly. Super engineering information could be derived from it. [redacted]

Such high energy radiation will have a comparatively long mean free path and some of it could pass directly from the DT through the transparent spot--which is the reason for aiming the spot at the DT. [redacted]

unwieldy. Wheeler raised a word of caution and pointed out that there could very well be some important reason for adding scopes beyond this figure which may show up in the theoretical considerations now being pursued.

In connection with the physical arrangements of looking at the two spots, York pointed out that a one-centimeter radius would seem to be the very minimum so that the x-ray equipment has a sufficiently large area to look at. In fact, the experimentalists would hope that the spots could be arranged to be of considerably larger radius. As will become apparent in Section F below, it will be useful to have the evacuated pipes leading to the spots of as large a diameter as possib

DoE
b(3)

DIII. Time Scale and Shape of Scope Traces.

Do

The question arises of how late a time after this first signal any x-ray record would still be of interest

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We are indeed interested, however, in times which occur after the DT mixture has burned because of engineering reasons.

DOE
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At the present time it is very difficult to make any predictions about the shape of the scope traces to be expected, but just in order to get some very qualitative feeling a given set of possibilities was sketched.

DOE
b(3

This is a crude guess. It is not certain that the initial rise and the rise due to the thermonuclear reaction will be separated.

E. [redacted]

EI. Number, Type and Location of Spots.

The Committee reaffirmed the decision that the two spots specified in Section F of the 10th minutes of the Committee were to be chosen for the X-ray experiment. [redacted] It is evident that the major use for the measurement of the mockup spot is from the point of view of a diagnostic experiment. [redacted] thus one might try to arrange this mockup spot in further designs in such a manner that it has as little of a covering surface as possible. However, this point is subject to further calculations and is not settled.

[redacted]

EII. Time Scale of Scope Traces.

[redacted]

F. Detecting Schemes for X-rays and Experimental Problems.

Bradner and York reported that about 12 detecting schemes had been under active consideration in Berkeley. Of these, there are two which are currently favored, which are discussed below.

1. "Fluorescence" detecting scheme. Figure 2 shows a schematic view. It is seen that the incident x-rays fall on a given fluorescing target. Secondary x-rays are emitted and counted by phototube detectors. It has not yet been decided whether these detectors will be cathodes with no covering, thus measuring the secondary x-rays directly, or whether they will be covered with a fluorescer in order to increase their efficiency. In view of results obtained by the Stanford group showing that terphenyl has a response time as short as 2 or 3 x 10^{-9} seconds, it is likely that a fluorescer will be used because the smearing of the time signal will not be very worrisome.

2. "Thick K edge filter" detecting scheme. Figure 3 shows a schematic view. The incident beam goes through a thick K edge filter, thus eliminating a certain portion of the spectrum. The spectrum is then narrowed down even further by passing the beam emerging from the K filter through a low pass filter. This low pass filter consists of a series of parallel plates at a very small angle to the beam (or the order of 1:600). X-rays which strike

one of the plates are totally reflected and if they are of the right energy will be reflected another time from the adjoining plate so that they fall upon the detectors. Recent experimental information from Kirkpatrick at Stanford shows that it is experimentally feasible to manufacture such low pass filters.

Clark expressed a preference for methods on which more experimental information is already available. According to his view, a differential method with measurements behind several consecutive K edge filters might be preferable. While this method suffers from the fact that it relies on small differences of large intensities, it has the advantage of tying in closely with older laboratory methods. York and Bradner reported that this method had been considered and that their method number 2 is actually a modification of this idea.

[redacted]

[redacted] It was agreed that some adaptation of the scheme described in Figure 2 of the Tenth Meeting such that the x-ray pipe would be considerably wider would be acceptable. Figure 4 shows such a modified layout where the x-ray pipe is as wide as the spot to be examined.

[redacted] Rather accurate corrections for the radiation leakage can be applied as long as the gap is so small.

[redacted] It was agreed that this would be preferable from the point

of view of heat conduction and no objection was raised to it from the point of view of x-ray transmission. This question will be discussed on June 22. Figure 4 shows one pipe for the DT spot and a corresponding pipe to be provided for the mockup spot. This scheme could of course be modified to permit one very large pipe to cover both spots and to have it branch into two pipes several meters below the spots.

DOE b(3)

However, to date no experiments have been provided for to give information about such an incipient reaction.

DOE b(3)

Such a step would of course be investigated in the tests following those of the Spring '51.

DOE b(3)

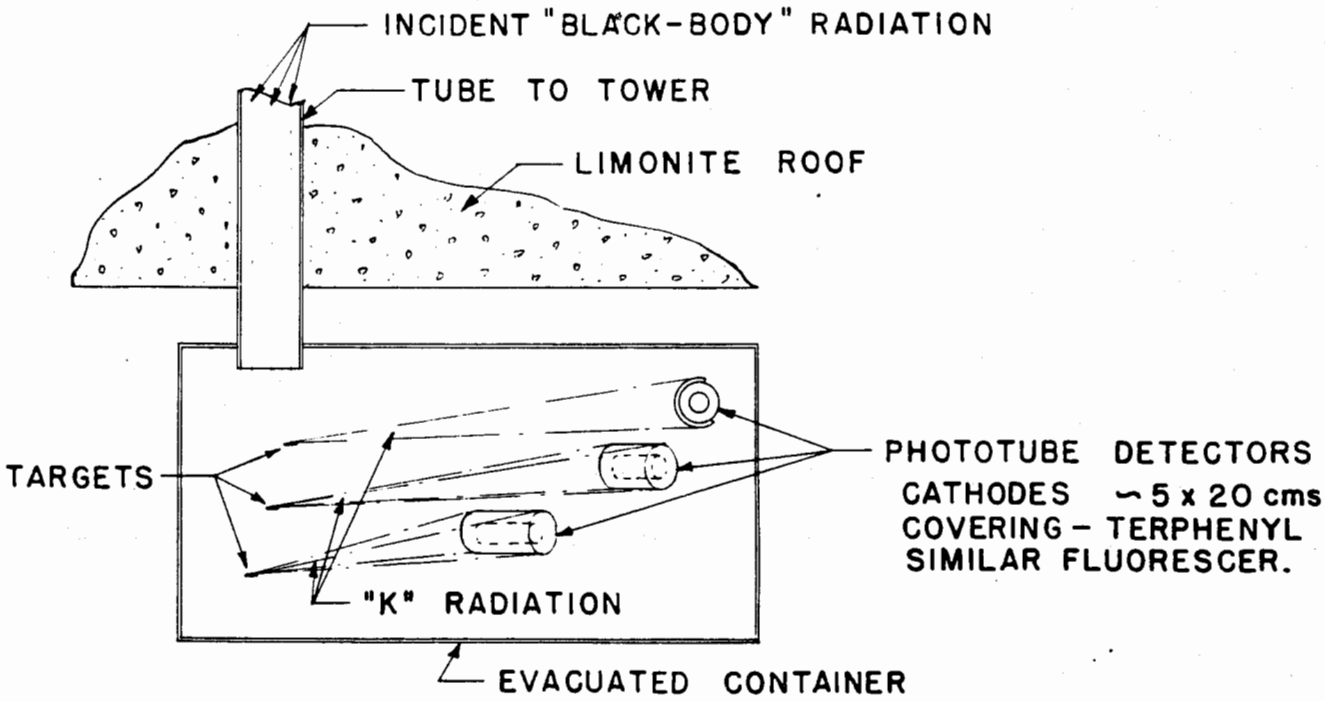
G. Next Meeting.

The next meeting which is to take place on Thursday, June 8, will examine the Argo-Agnew report on neutron experiments. Agnew, Argo, Hall, King, Ogle, and Reines are to be invited to this meeting. A report on the Hippo calculations will be given.

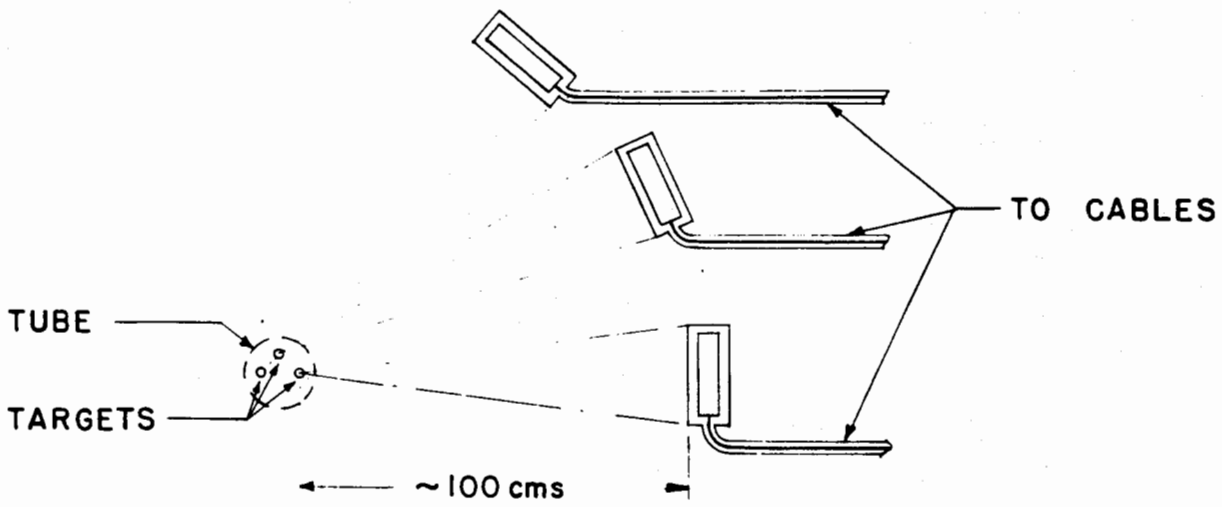
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PLAN

FIG. 2
"FLUORESCENCE" DETECTING SCHEME

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FAMILY COMMITTEE
Minutes of Thirteenth Meeting
June 8, 1950

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A. Attendance.

The thirteenth meeting of the Family Committee was held Thursday, June 8, 1950 at 1:15 P.M. in Room B-117. Those present were:

H. M. Agnew	E. R. Jette
H. V. Argo	D. P. MacDougall
J. C. Clark	J. C. Mark
F. de Hoffmann	W. E. Ogle
D. K. Froman	F. Reines
R. W. Goranson	F. Seitz
A. C. Graves	R. F. Taschek
D. B. Hall	E. Teller, Chairman
M. B. Holloway	

B. Minutes of the Twelfth Meeting.

The Committee unanimously adopted the minutes of the Twelfth Meeting reported in ADWD-146, with the following additions and corrections:

(1)

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(3)

(2)

C. TENEX.

Agnew gave a summary of the conclusions which had led him and Argo to report favorably on the possibility of performing TENEX for the Spring '51 tests. (These arguments are outlined in detail in ADWD-142.) It was estimated that about two scopes would be required at both stations with possibly some more scopes as a timing tie-in. The scope figures are here reported in order to give an indication of the order of magnitude involved. The distant station is needed to measure the energy spread due to temperature in the 14 mev neutrons. The close station establishes the fact that the actual DT reaction occurred in a time short compared to the time signal in the distant station. The low number of scopes, in spite of the large ranges to be covered, is due to the fact that soft scopes, that is scopes driven at low voltage, will suffice for the time resolution required in this experiment.

It was reported that most likely the detecting chambers in the TENEX experiment would be of the hydrogen recoil type rather than fission chambers since in the former case one can get many more atoms per cm^2 so that the

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reiterated a statement he had made in previous meetings that at the present time all information concerning crystal response could only be put into the class of "guesswork" because the experiments concerning these crystals were still in progress at various laboratories throughout the country and the results still seem to differ by large factors. Moreover, Taschek remarked that such crystal response would have to be studied under large current drawing conditions.

It was agreed that if the fall time were larger than one shake, then the advantages with respect to timing of FLUNEX over TENEX would be nil. However, if the effective fall time is less than or about a shake, then FLUNEX will give information about the crucial induction time in the case of a fizzle, whereas TENEX would not have sufficient time resolution.

Discussion took place concerning the way one would establish a fiducial timing mark for the FLUNEX experiment. Two possibilities present themselves:

(1) Observation of the point at which the curve breaks away from the constant alpha region and comparison with the theoretical time at which this should take place.

(2) An absolute calibration of the number of neutrons falling on the fluorescer by means of comparison with such experiments as ANEX or PHONEX.

It was noted that in the experiment as proposed by Teller, some cables and some shielding of these cables would be necessary, which is a deviation from the originally proposed experiment--not now deemed advisable because of the scattering in air. Reines pointed out that if one only wanted to obtain information in the DINEX experiment concerning the shape of the 14 mev neutrons, without much regard to absolute values, one might be able to eliminate a considerable amount of the shielding required for DINEX. It was noted, however, that in the case only a very small fraction of the DT burned, elimination of such shielding may give rise to difficulties in DINEX, due to swamping of the 14 mev neutrons by neutrons of lower energy, such as 5 mev. In the case of FLUNEX one would have the advantage that the distance at which the crystal is placed automatically insures some time of flight separation between the 14 mev and 5 mev neutrons.

The group then proceeded to try to examine whether in view of the above discussion it should recommend that the FLUNEX experiment was very worth while performing in addition to the other experiments now planned for the Spring of '51. Teller stated that he felt that insurance for the DINEX experiment was definitely needed and suggested that the Family Committee request appropriate people to make more detailed studies in the immediate future to determine the experimental feasibility of incorporating FLUNEX in the Spring '51 tests. He felt that the loss of data which would result in the case of a complete DINEX fizzle would be very serious and that the FLUNEX effort would definitely be warranted unless it proved to be an experimental monster.

Taschek, Froman, the experimentalists present and others felt that the insurance obtained from FLUNEX is not likely to counterbalance the detracting effect that the FLUNEX experiment would produce. In particular, they believe that such an experiment is of considerable magnitude because the experimental data on which it is to be based do not yet exist, and that there is no certainty that they can be obtained in time--at least without disrupting efforts which must proceed on DINEX and other larger experiments now scheduled for the Spring of '51. Graves reported that J-Division would have to know within the order of two or three months whether FLUNEX would be incorporated or not in order to make experimental arrangements at Eniwetok. (The outside time limit would assume that certain construction items on the testing tower and at the bottom of it would be irreversibly frozen and the FLUNEX experiment would have to adjust itself to the given physical conditions.)

The Committee found it impossible to resolve the conflict concerning what scale of possible effort (ranging between a nil and a full-fledged effort) would be recommended with respect to FLUNEX. In view of this, the Committee requested that Graves examine the situation further and, keeping in mind the commitments made at this meeting, make a decision concerning the scope and type of effort which should be expended on FLUNEX. It was requested that Graves report his conclusions to the Family Committee.

DOE b(3)

E. [redacted]

Goranson summarized the conclusions incorporated in Konopinski's and his memorandum of June 7, which is included as Appendix A to these minutes. It was noted that the sketch represented in Figure 1 of Appendix A represents a revision of Figure 6 of the Eleventh Minutes. [redacted]

DOE b(3)

F. Future Meetings.

DOE b(3)

[redacted]

DOE b(3)

The subsequent meeting will take place on Wednesday, June 28th. [redacted] The following are to be

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INTER-OFFICE MEMORANDUM

APPENDIX A

Date 7 June 1950

TO: - The Family Committee

FROM: Emil Konopinski and Roy Goranson

SUBJECT:

DOE b(3)

REF: ADND-3-3

PART I. THEORETICAL CONSIDERATIONS

Presented herewith are the results of discussions in which the following have participated: Teller, Goranson, Mark, Wheeler, Smith, Taylor, Hammer and Konopinski.

DOE b(3)

The types of advantage considered as possible are:

1. The increased H.E. dimensions will result in a greater compression of core and tamper if their mass is unchanged or if their mass is not scaled up fully together with the H.E. dimensions. The greater compression will produce higher central temperatures. This is partially offset, as far as the yield of radiation is concerned, by the greater density of core material which the radiation must penetrate on its way out.

2. The tamper may be thickened.

DOE b(3)

3.

For a more quantitative comparison of the above advantages, Wheeler proposed as a criterion that the quantity

E

should be maximized. Here φ is the undepleted efficiency, which primarily determines the temperature.

DOE b(3)

The second column of the table gives the mass of 25 in kilograms. The third column gives the radius R of the compressed 25 in cm.

DOE b(3)

ρ/ρ_0 is the core compression. φ and φ' are undepleted and depleted efficiencies, respectively. The column headed Y gives the expected final yields in kilotons. The final column lists the values for Wheeler's criterion.

The next two lines deal with models obtained by scaling up all radial dimensions from the first line, so as to keep the same compression.

DOE b(3)

The models of lines 5 and 6 keep the same mass of tamper as obtained in line 3.

DOE b(3)

Calculations at present indicate that this yield will be needed to assure adequate radiation temperatures.

The tamper mass in the line 6 model is the same as in lines 3 and 5

DOE b(3)

The latter model has the added advantage that it

makes the early energy evolution more secure against interruption by the tamper rarefaction. It is the model of line 6, therefore, which is recommended as the result of these discussions.

One qualification upon this recommendation was pressed by Teller.

DOE b(3)

This may constitute a hazard for the observers of the test, for the observation records of the test, or for the sites of subsequent tests. The main argument for the existence of this small chance of an excessive yield is the following: The Hippo calculations lead to much higher yields than were actually observed at Trinity.

DOE b(3)

PART II - DESIGN CHARACTERISTICS

DOE b(3)

The figures are drawn to scale as presently conceived. However, dimensions have been omitted where there exists a possibility that later minor modifications may be found to be advisable.

DOE b(3)

In Table II

DOE b(3)

These figures are compared with the three earlier preliminary design considerations listed in columns 1 to 3 inclusive.

I.B.M. calculations have been made on F-4 and F-5.

DOE b(3)

The implosion of F-4 on 0.7 scale and of F-6 on 0.6 scale have also been studied photographically and by the pin technique. Compressions given in the third and fourth columns are estimated from those calculated for the first two columns.

DOE b(3)

DOE
b(3)

There exists a small but finite probability (perhaps 5%) that the calculated efficiency may be underestimated by a factor of 50% (or perhaps even by 75%).

DOE
b(3)

). It should be pointed out, however, that the pre-detonation probability (a fizzle) is expected to be greater than the probability of an excessive yield.

DOE
b(3)

Emil Konopinski
Roy Goranson

RWG:rvc

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ADWD-153

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LAMD-332

FAMILY COMMITTEE
Minutes of Fourteenth Meeting
June 22, 1950

SRA-2000-0215-C

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
1ST REVIEW-DATE: 8/16/97 AUTHORITY: DADC DADO NAME: 2nd REVIEW-DATE: 4/13/47 AUTHORITY: ADD NAME:
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A. Attendance.

The fourteenth meeting of the Family Committee was held Thursday, June 22, 1950 at 1:15 PM in Room B-117. Those present were:

J. C. Clark	J. M. Keller
F. de Hoffmann	D. P. MacDougall
B. Freeman	J. C. Mark
D. K. Froman	R. D. Richtmyer
R. W. Goranson	R. E. Schreiber
A. C. Graves	R. F. Taschek
E. F. Hammel	E. Teller, Chairman
E. R. Jette	J. A. Wheeler

B. Minutes of the Thirteenth Meeting.

The Committee unanimously adopted the minutes of the Thirteenth meeting, reported in ADWD-148.

C. [redacted]

[redacted] This was the design considered to date (see for example, Fig. I of the 10th Minutes) and for ease of reference we shall call it "[redacted]nventional" design in these minutes. [redacted]

[redacted] Profiles for the rate of [redacted]

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FAMILY COMMITTEE
Minutes of Twenty-First Meeting
August 26, 1950

UNCLASSIFIED

Note call for 500 tons of lead for DINEX experiment on page 2 (large amount of lead was used in the 1958 Hardtack-Cactus test, creating a few intense but extremely localised hotspots of metal debris "fallout" near the crater).

A. Attendance.

The twenty-first meeting of the Family Committee was held Saturday, August 26, 1950 at 9:00 A.M. in Room B-117. Those present were:

N. E. Bradbury	E. R. Jette
J. C. Clark	M. H. Johnson
F. de Hoffmann	D. P. MacDougall
E. Fermi	R. D. Richtmyer
D. K. Froman	R. W. Spence
R. W. Goranson	E. Teller, Chairman
D. B. Hall	F. Walters
E. Krause	J. A. Wheeler
M. G. Holloway	C. V. Strain

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
1ST REVIEW-DATE: 8-17-94
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AUTHORITY: ADD
NAME: [illegible]
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B. Minutes of the Twentieth Meeting.

The Committee unanimously adopted the minutes of the Twentieth Meeting reported in ADWD-176 with the following correction: DOE b(3)

[redacted]

C. DINEX vs. GANEX.

Dave Hall reported that a meeting on the subject had been held with the NRL group all of Friday, August 25th. These discussions led to the feeling that basically DINEX and GANEX had the same chance of yielding information on the time dependence [redacted] DOE b(3)

There seemed to be weight given to two points in favor of GANEX. The first one of these concerned itself with the fact that the DINEX shield, as previously noted in these minutes, gives rise to interference with experiments such as ball of fire, TENEX, PHONEX and ANEX (up to recently no alternative to DINEX was available so that this interference had to be tolerated; now one is in a position of minimizing this interference in replacing DINEX by GANEX). The second point concerned itself with the feeling that the radio-chemistry would suffer appreciably due to the great amount of lead present in the DINEX shield (this point was cleared up during the course of the present meeting and is discussed further on in these minutes).

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In view of the Friday meeting, Hall submitted a possible program for discussion:

1. DINEX effort continued but is cut back to the extent that parts dealing with insuring energy level measurement such as absorber-scatterer measurements are eliminated.

2. GANEX be engineered.

3. At the earliest possible time but not later than January 1, 1951, decide on either GANEX or DINEX but decide at once that no combination of the two should be used.

Considerable discussion ensued concerning this proposal. Krause raised the point that one of the difficulties in successfully planning any program was that connected with the uncertainty of what kind of gadget would be shot.

[redacted]

DOE b(3

Rod Spence was asked to join the group at this point to evaluate the difficulties the DINEX shield would present with respect to the radiochemical program. He was able to report that the difficulties would not be as great as anticipated. In particular, it has now been established that the filter papers would not be clogged--rather the difficulty would arise from the amount of tungsten and uranium contained as impurities in the approximately 500 tons of lead required for DINEX. Spence hopes that it will be possible without too much difficulty to analyze representative samples of the lead used for uranium and tungsten and make appropriate corrections. While this will lower slightly the accuracy of the radiochemical method, it is not believed that this would be a sufficiently strong argument against the use of DINEX.

Krause suggested that it may be advisable to carry on a program which would result in a shot with a cut back DINEX and GANEX (where GANEX also would be kept to its essentials, that is for instance, one would not indulge in the luxury of measuring fission neutrons by GANEX). In this case, the logistic effort would be planned such that DINEX and GANEX jointly would not exceed the logistic effort of the full scale DINEX alone. Clark reported that from the point of view of J Division, it would be acceptable to plan for either DINEX alone, GANEX alone or a combination in the manner just indicated.

J Division could hold up on the decision to build a limonite column for DINEX as late as November 1, 1950. On the other hand, arrangements for the 200 ton tower should probably be made immediately.

Wheeler emphasized that the NRL group should be given as much freedom of decision as possible in view of the fact that they are the group that will actually have to take the experimental responsibility for the success of the experiment. The group strongly supported this view. Fermi expressed the view that possibly the instrumentation of both DINEX and GANEX might lead to too much effort being put into these experiments but agreed that this depended to a large extent on how much NRL itself felt it could carry. Holloway dissented strongly from the majority view and thought that it was too late to introduce a new experiment such as GANEX into the schedule and that one would have to have strong reasons forcing one to include GANEX. He would think it preferable if DINEX were to be instrumented to completion now and the schedule adhered to.

[redacted] DOE 6(2)

Probably the ball of fire would be most strongly affected and TENEX least. In view of the possibility of replacing DINEX by GANEX, it was thus recommended that J Division re-examine the extent of interference of the DINEX shield, particularly because PHONEX and ANEX were currently thought of as rather valuable and simple experiments.

In view of this situation, the following summary was agreed upon:

1. The NRL group should have as much influence as possible in deciding questions of DINEX and GANEX.

2. Re-evaluation should be undertaken immediately concerning the interference of the DINEX shield with the ball of fire, ANEX, PHONEX and TENEX.

3. If this re-evaluation shows that the interference is very considerable, then it is believed NRL may want to concentrate on GANEX and carry along DINEX only as insurance if GANEX should show up flaws.

4. If this re-evaluation shows that the interference is either tolerable or can be circumvented by calibration methods and other experiments then the NRL group would try to reach a decision whether or not to carry on DINEX only, GANEX only, or a combination of the two requiring no more than the original logistic effort envisaged for DINEX.

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FAMILY COMMITTEE
Minutes of Twenty-Fourth Meeting
October 5, 1950

ADWD-197

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A. Attendance.

The twenty-fourth meeting of the Family Committee was held Thursday, October 5, 1950 at 1:15 PM in Room B-117 and Friday, October 6, 1950 at 9:00 A.M. in Room G-246. Those present were

G. H. Best	J. H. Manley
N. E. Bradbury	D. P. MacDougall
J. C. Clark	J. C. Mark
F. de Hoffmann	L. B. Seely
D. K. Froman	R. F. Taschek
R. W. Goranson	E. Teller, Chairman
A. C. Graves	J. L. Tuck
G. K. Hess	H. F. York
M. G. Holloway	

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
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7. OTHER (SPECIFY):

B. Minutes of the Previous Meeting.

The Committee unanimously adopted the minutes of the twenty-third meeting reported in ADWD-194.

C. Booster.

[redacted]

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Correction made on Page 3. 10-11-50 V.H.

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[redacted] DOE (3)

[redacted] The rough estimates show that this is not likely to give trouble but it is believed that this point should be examined more carefully. [redacted] DOE (3)

[redacted] The resultant increase in volume is quite small. It was agreed that T Division would inform the members of the Family Committee by Monday whether or not it would be advisable to move the bottom down by the one-half centimeter.

[redacted] DOE (3)

I. X-Ray Experiment.

York reported that it was presently planned to close off the top of the vacuum tube by a 1/4 inch thick beryllium plate. If calculations and experiment prove that a thinner alluminum or magnesium plate will serve the same purpose, this may replace the beryllium. [redacted] DOE (3)

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ADWD-217

FAMILY COMMITTEE
Minutes of Twenty-Seventh Meeting
November 15, 1950

-1-

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NAME: 5. CLASSIFICATION CANCELLED
6. CLASSIFIED INFO BRACKETED

SAP 20000992 CCCC
Unique Document #

A. Attendance.

The twenty-seventh meeting of the Family Committee was held Wednesday, November 15, 1950 at 1:15 PM in Room B-117. Those present were:

N. E. Bradbury	M. G. Holloway
J. C. Clark	E. R. Jette
F. de Hoffmann	D. P. MacDougall
D. K. Froman	J. C. Mark
R. W. Goranson	E. Teller, Chairman

B. Minutes of the Twenty-sixth Meeting.

The Committee unanimously adopted the minutes of the twenty-sixth meeting as reported in ADWD-206 with the following corrections:

On page 2, in the sixth line of the first paragraph of Item D, the word "radium" should read "radius".

On page 4, 5.11.2, substitute 3/8" instead of 3.8".

C. [redacted] DOE 5(3)

The Committee discussed memorandum CMR-9-261 from Ed Hammel to de Hoffmann, which is attached to these minutes as Appendix A. [redacted] DOE b(3)

D. Scope of Committee Work.

In line with the discussions reported under Item E of the twenty-sixth minutes, the Director presented his views concerning the scope of the work which the Committee should undertake. Bradbury reiterated that basically his original directive envisaged the Committee to be one that would deal with all the thermonuclear phases of the laboratory program.

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He recognized that in line with the current laboratory program Greenhouse had taken up almost the entire time of the Committee. It is hoped, however, that from now on the Committee will be able to turn its attention in an increasing manner to those phases of the laboratory program on thermonuclear work that should be undertaken after Greenhouse and to long range questions of achieving any kind of thermonuclear weapon. It was agreed that the Committee should not restrict its attention solely to super-type weapons but that such items as the alarm clock, boosted weapons, etc., should also be examined.

As to the procedural way in which the Committee is to operate, the Director expressed the hope that the Committee would continue to be essentially a "line function" type structure so that the Director could look to it both for direction as well as action in the thermonuclear field.

E. Longer Range Problems.

Teller reported on the status of some current calculations and ideas and these are summarized below.

[redacted] DOE b(3) This has been necessitated by the fact that almost all theoretical manpower available has been needed to make detailed calculations for Greenhouse and because some of the work is, of necessity, shifting towards a more detailed examination of the inverse Compton effect as detailed below.

[redacted] DOE b(3) DOE b(2)

2. Boosted Weapons.

At the moment essentially no effort is being devoted towards the further exploration of boosted weapons. This has come about almost automatically since the lack of theoretical manpower (between that needed for

Greenhouse and that going into ignition and propagation considerations for the super) did not permit this work to be carried on. Since the boosting principle would be of greatest interest for small weapons, it was agreed that the lack of effort on this problem was reasonable until after such a time as small weapons were explored more completely at Greenhouse.

[redacted] DoE b(3)

3. Alarm Clock.

[redacted] DoE b(3)

It is recognized that the volume involved would be quite large since the final yield is determined

by the total volume. It should be emphasized strongly that these estimates of the initial conditions required are exceedingly uncertain.

[redacted]

DOE b(3)

In view of this the possibility of performing machine calculations is being explored. Such a machine calculation would tell one more definitely whether the alarm clock idea was worthwhile and if so in what direction it should be pursued.

[redacted]

DOE b(3)

4.

[redacted]

DOE b(3)

[redacted]

DOE 6(3)

5. Magnetic Fields.

Several years ago, it was recognized that one could improve the chances of making a workable super by the use of very large magnetic fields. Such magnetic fields would have two beneficial effects, namely:

[redacted]

DOE 6(3)

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FAMILY COMMITTEE
Minutes of Twenty-Ninth Meeting
December 21, 1950

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AUTHORITY: CADC CADC ADD
NAME: Allen Hughes
2ND REVIEW-DATE: 9/18/97
AUTHORITY: ADD
NAME: [illegible]

A. Attendance.

The twenty-ninth meeting of the Family Committee was held Thursday, December 21, 1950 at 1:15 PM in Room B-117. Those present were:

G. H. Best
N. E. Bradbury
F. de Hoffmann
D. K. Froman
D. B. Hall
G. K. Hess
M. G. Holloway
D. P. MacDougall
J. C. Mark
L. B. Seely
R. F. Taschek
E. Teller, Chairman
F. M. Walters

B. Minutes of Twenty-eighth Meeting.

The Committee unanimously adopted the minutes of the twenty-eighth meeting as reported in ADWD-223.

C. Booster.

[redacted] (See item 10, page 5 of the minutes of the 26th meeting.)

[redacted]

Sandia has furnished samples of the actual sphere cases which will be used for the Greenhouse units.

[redacted]

D. [redacted]

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3. Aluminum Plug.

[redacted] DOE (C)

In consequence, it would not be desirable to make the aluminum plug out of 24S aluminum. The Committee therefore requested that the aluminum plug be manufactured from 2S aluminum and also that a sample be saved for analysis of impurities.

[redacted] DOE b(3)

After this discussion the following position was arrived at. [redacted] DOE b(3)

A discussion of these items is reserved for January 4 and 11. There follows below a summary of the discussions concerning each item. Hall and Seely presented the status of each experiment.

1. DINEX

It is planned that the experiment cover an intensity range slightly greater than a factor 10^7. This will be done by having two channels record the proton recoils from the 14 Mev neutrons. One channel will only be sensitive to very high signals. Thus it is hoped that the peak from the DT burning can be recorded although its shape will not be known accurately. [redacted] DOE (C)

It will be recalled that the signal is fed from the tower to ground through shielded co-axial cables and NRL is confident that sufficient shielding has been provided. [redacted] DOE b(3)

It would seem that anything greater than 1% burning of the DT should be detected successfully by DINEX. It was estimated that the chance of DINEX performing as expected was rather better than even.

2. GANEX (Note: neutrons were converted into gamma signals by the use of iron GANEX "converters" in Ivy-MIKE shot of1952 according to the film, "Operation Ivy")

It will be recalled that GANEX used natural uranium as a gamma converter. Experiments during the summer indicated that iron would result in a higher gamma conversion. In consequence, NRL presently plans to use 3 cm of iron for the gamma converter. Taschek expressed some doubts concerning the reality of the iron results and it was agreed that it might be useful to consider backing up the iron by uranium or perhaps to replace the last centimeter of iron by uranium.

It was noted that GANEX would not yield an absolute value of the 14 Mev neutrons and that the uranium scheme would therefore not introduce any calibration difficulties.

It is expected that GANEX would successfully record the burning of more than a few percent DT.

3. PHONEX

If fogging of plates by gamma rays can be prevented, PHONEX is likely to give the most reliable single number for the quantity of DT that has burned. Probably this number should be good to ± 15%. This is likely to compare favorably with the results from the n,2n experiment which is not reported upon at this meeting.

4. ANEX

Some trouble has been encountered with ANEX. Activation functions of such elements as sulfur seem to vary sharply over the region of interest (i.e., within a few Mev). This throws some doubt on the interpretation of results that might be obtained.

5. TENEX

There are two stations for TENEX, one at 200 yards, to determine burning time, and one at 1000 yards to determine temperature. It is estimated that TENEX has a better than even chance of giving usable results.

6. X-RAY

Brahner, in cooperation with Jacot, has furnished two figures concerning how the present setup looks. These are attached.

At present each spot provides for two sets of independent measurements. In each case detectors have been so arranged that the difficult effect of lines in the spectrum can be subtracted off in evaluating the results. Theoretical work has proceeded on the interpretation of the iron and combination spot at Berkeley.

Attention has been given to the question of closing up of diaphragms but there is still some danger from this phenomenon.

It should be noted that the experiment can not be "tested" with a dry run.

While it is dubious whether all aspects of the X-RAY experiment will work simultaneously, it is believed that the chance that the X-RAY experiment will give useful information is quite high. For instance, the experiment has now been so designed that even if intensities and temperatures are not recorded properly, quite a bit of information can be obtained from breakthrough times through the iron and combination spot.

F. Next Meetings.

The next meetings of the Committee are to take place on Thursday, January 4, 1951 and Thursday, January 11, 1951.

Executive Secretary

Distribution:

1A N. E. Bradbury
2A W. C. Bright
3A S. W. Burriss
4A J. C. Clark
5A D. K. Froman
6A R. W. Goranson
7A A. C. Graves
8A G. K. Hess
9A M. G. Holloway
10A E. R. Jette
11A " " "
12A J. M. B. Kellogg
13A J. L. Tuck
14A D. P. MacDougall
15A " " "
16A D. P. MacMillan
17A J. H. Manley
18A J. C. Mark
19A H. C. Paxton
20A F. Reines
21A " "
22A " "
23A A. R. Sayer
24A R. F. Taschek
25A E. Teller
26A " "
27A " "
28A " "
29A " "
30A J. von Neumann
31A J. A. Wheeler
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33A " "
34A " "
35A " "
36A " "
37A " "
38A " "
39A C. Longmire
40A R. W. Spence
41A A. C. Graves
42A R. C. Smith
43A W. E. Ogle
44A E. Teller
45A " "
46A " "
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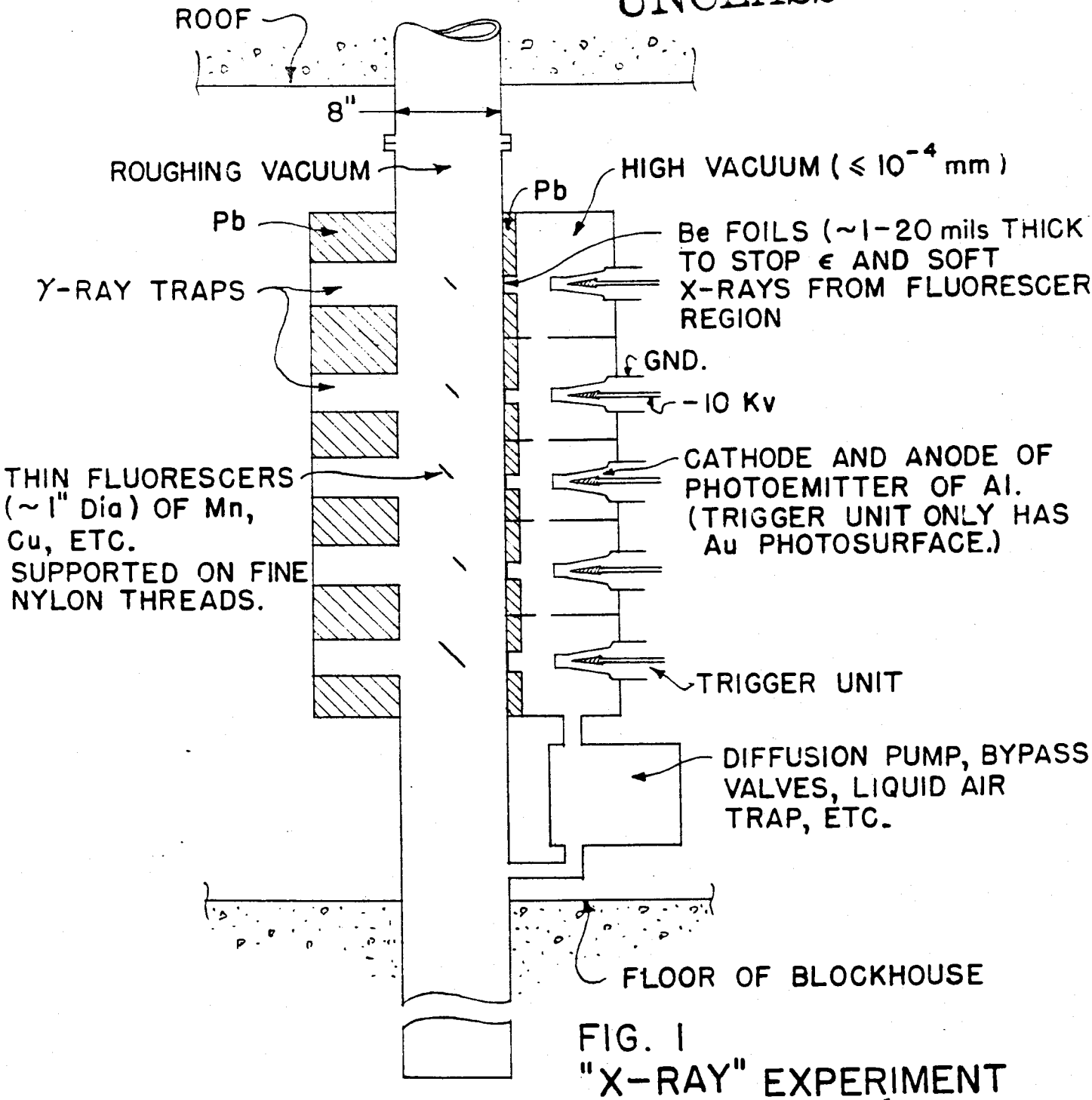
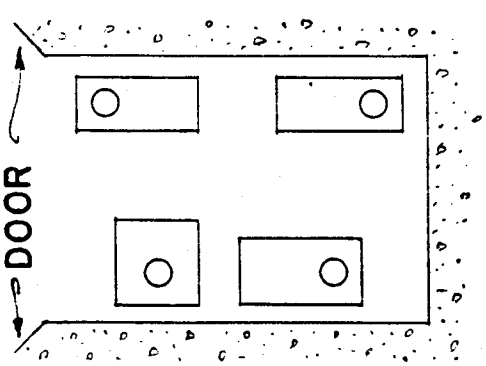


FIG. 1
"X-RAY" EXPERIMENT



PLAN OF BLOCKHOUSE
ARRANGEMENT

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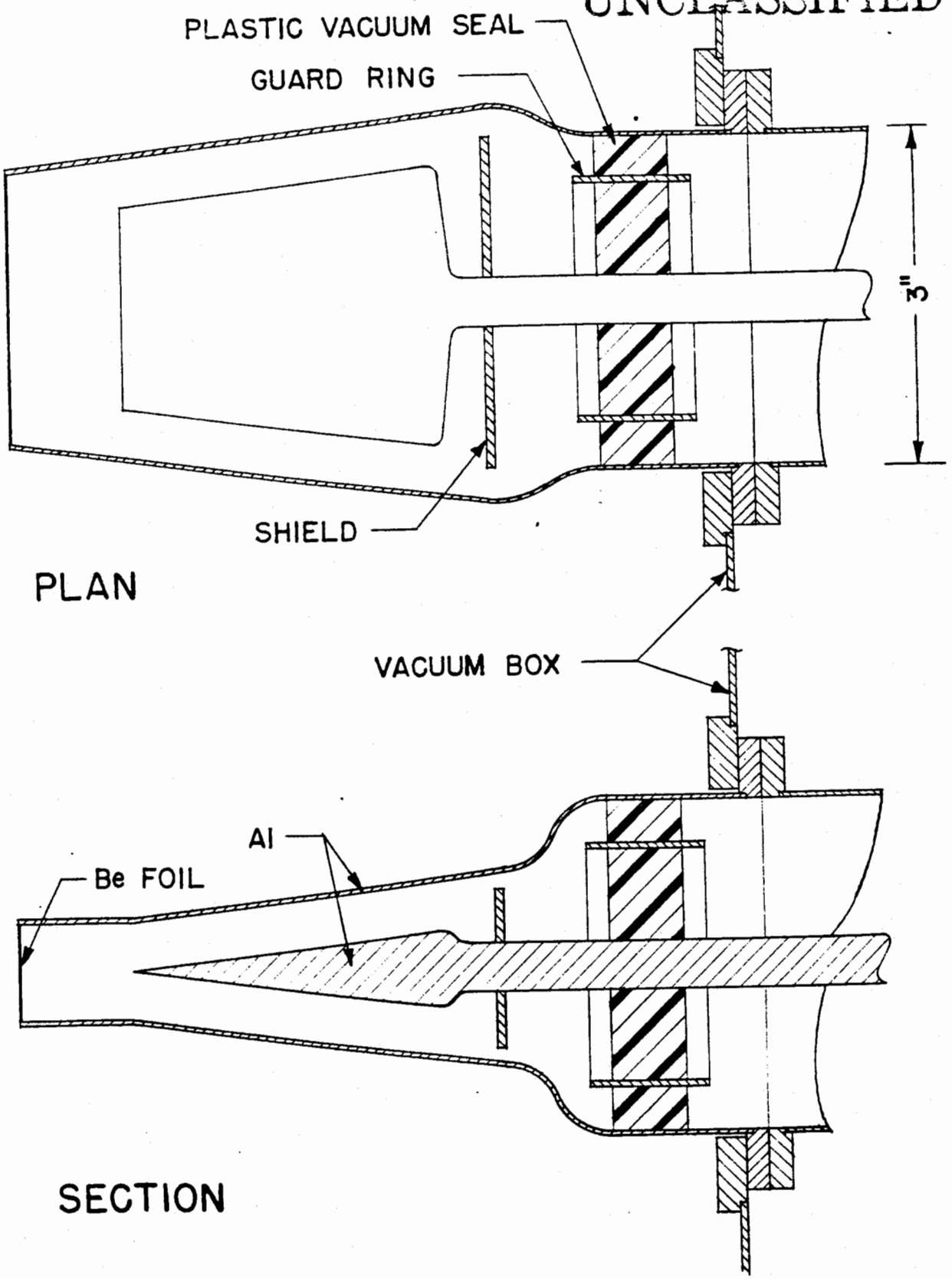


FIG. 2
"SHOVEL" DETECTOR

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February 14, 1952

MINUTES OF THE SEVENTEENTH MEETING OF THE THEORETICAL MEGATON GROUP

13 February 1952

1. The seventeenth meeting of the TMG convened at 9:00 AM on Wednesday, February 13, 1952 in the W-Division Conference Room. Those present were:

H. M. Agnew	R. M. Landshoff
G. Bell	R. B. Lazarus
H. A. Bethe	C. L. Longmire
W. Bouricius	J. C. Mark, Chairman
A. A. Broyles	N. Metropolis
F. de Hoffmann	L. W. Nordheim
J. J. Devaney	L. G. Peck
B. E. Freeman	J. R. Reitz
D. K. Froman	A. Rosenbluth
W. B. Goad	J. L. Tuck
G. M. Grover	S. M. Ulam
F. C. Hoyt	G. M. Wing

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7. OTHER (SPECIFY):

2. [redacted]
A second casting has proved to be free from this defect.

DOE b(3)

3. Implosion and Burning Calculations on the SEAC. No new results from the 100 mass point coding now being perfected have as yet been received in Los Alamos.

[redacted] It is expected that this Matterhorn study of burning and propagation will be completed in a matter of weeks.

DOE b(3)

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4. [redacted] de Hoffmann reported on a calculation now being set up in cooperation with Rand which will give quick results, by hand computation, for the temperature in the implosion channel as a function of position and time. [redacted]

5. [redacted] The results obtained, which still contain uncertainties due to imperfect statistics with only 1016 neutron samples, agree with the earlier estimates to within about 10%. [redacted]

6. [redacted]

8. Preliminary Planning for an Alarm Clock Test. Mark reported on current thinking in the Laboratory Director's Office on the scheduling and philosophy of an eventual alarm clock test. [redacted]

1) It was erroneously reported in the 15th Minutes that a disintegration cross section of .1 barn was included in these Rand calculations. Actually, a calculation including disintegration of the deuterium has not yet been carried out.

DOE
b(3)

[redacted] The objective should be to test the design of a weapon giving the largest yield consistent with delivery from an existing aircraft or one that will be available at a predictable date.

9. Airplane Characteristics. Some pertinent information on the types of military aircraft that should be considered for delivery of a thermonuclear bomb such as the alarm clock was presented by Agnew and is summarized in the accompanying table.

As a guide to military planning and delivery of a thermonuclear bomb, the following specifications on weight and size have been tentatively proposed: Weight 50,000 lbs; length 20'; diameter 6'. The "compatibility" in the last column of the table is with respect to these specifications.

There are expected to be about 200 B-36 D planes available in 1953-54. The YB 60 and XB 52 will become operational during 1954, with 10 of each in operation. The B-47B is operational at present, though the modifications necessary to carry the 50,000 lb. bomb load are not yet incorporated.

Frank C. Hoyt

[redacted]

(5)

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Type	Gross wt at take-off in lbs	Bomb load in lbs	Weight of fuel in lbs	Combat radius in nautical miles	Bombing altitude in feet	Cruising speed in knots (maximum speed)	Compatibility with thermonuclear bomb
B-36 D	357,500	50,000	131,043	1,920	40,000	290 (360)	Fits
	357,500	86,000	91,489	1,485	25,000	190 (325)	Fits
	357,500	10,000	170,000	2,870	40,000	(353)	Fits
XB 60	410,000	50,000	221,000	2,550	42,500	400 (440)	Fits
	410,000	72,000	197,498	2,125	42,500	399 (440)	Fits
	410,000	10,000	260,800	2,910	44,800	400 (440)	Fits
XB 52	390,000	50,000	180,450	2,460	45,000	457 (480)	Requires fuel tank modification.
	390,000	10,000	219,240	3,070	46,500	457 (480)	
B-47 B	185,000	50,000	50,360	<1,000	<40,000	445	Redesign of fuselage required.
	180,000	10,000	87,300	2,130	41,000	445	
		50,000		4,000*			

*One way, with two refuellings.

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February 28, 1952

Mike test: separate calculation algorithms used for (a) radiation flow then separately (b) deuterium fusion (burn).

MINUTES OF THE NINETEENTH MEETING OF THE THEORETICAL MEGATON GROUP

27 February 1952

1. The nineteenth meeting of the TMG convened at 9:00 AM on Wednesday, February 27, 1952 in the W-Division Conference Room. Those present were:

G. Bell	F. C. Hoyt
H. A. Bethe	R. M. Landshoff
W. Bouricius	P. Lax
A. A. Broyles	C. L. Longmire
E. D. Cashwell	J. C. Mark, Chairman
R. Courant	N. Metropolis
F. de Hoffmann	L. W. Nordheim
J. J. Devaney	L. G. Peck
B. E. Freeman	O. W. Rechard
W. B. Goad	F. Reines
R. W. Goranson	R. D. Richtmyer
G. M. Grover	M. Rosenbluth
M. G. Holloway	J. L. Tuck

S. M. Ulam

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3. SEAC Problems

[redacted]

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[redacted] In this connection it would be useful to insert a factor for rate of rise of temperature.

Richtmyer has begun coding a problem for detailed study of surface motions.

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The effect of varying the "explosive" will also be looked into, i.e. density variations in the interval 0.02 to 0.1 and associated temperatures for a certain total available energy.

4.

DOE
b(3)

5. Flow of radiation (de Hoffmann)

DOE
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8. [redacted]

DOE b(3)

9. Burning calculations (Peck)

The calculation will follow the burning of D out from the center as far as one's interest extends.

[redacted]

DOE b(3)

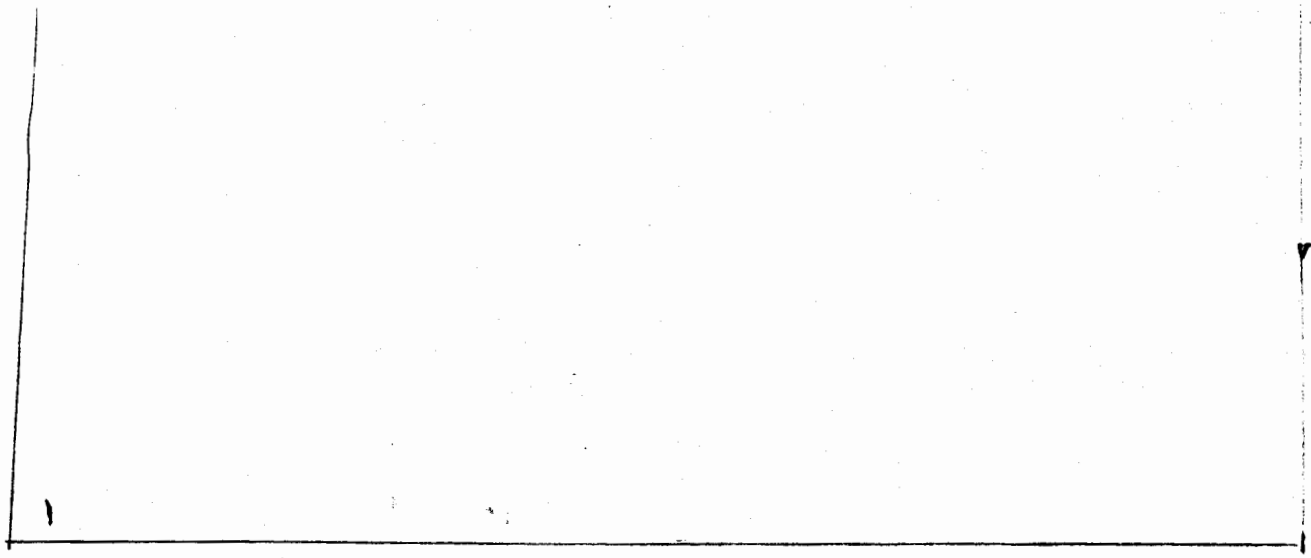
DOE b(3)

An expression similar to that used for AC calculations to account for the temperature dependence of opacity:

[redacted]

DOE b(3)

20th Meeting of the Theoretical megaton Group, 1952: radiation flow and heat capacity as function of temp.



Varying the temperature does not help matters because at low temperatures radiation flow and heat capacity each vary about as T^3 so that the time required for heat flow, which depends on their ratio, will be unchanged. At higher temperatures radiation flow varies as T^2 and heat capacity as T^3, with consequent loss.

Bethe, Broyles, and Freeman will prepare a problem for either CPC or SEAC operation which is expected to give a good treatment of propagation along the channel.

7. Experiments planned for Snapper.

J-Division's primary interest is to investigate experimental techniques proposed for the Ivy test.

Zero time would be obtained from an external phosphor.

The streak cameras have, in principle, a 2 shake resolution time but the over-all time uncertainty was expected to be perhaps 10 shakes. Framing cameras with 1/3 μsec resolution will obtain over-all pictures of the gadget.

The uncertainties discussed in the above sections have enhanced the interest of TMG in this experiment. In consequence, during a discussion following the regular meeting, certain modifications of the original design were requested.

Certain other kinds of observations and other observational positions were discussed but no final decisions on these were reached at this meeting. It was first stated that 8 to 10 observational spots was a maximum; it appeared later that by avoiding some duplication this number could be extended if desirable.

R. W. Goranson

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June 3, 1952

MINUTES OF THE TWENTY-NINTH MEETING OF THE THEORETICAL MEGATON GROUP

28 May 1952

1. The twenty-ninth meeting of the TMG convened at 9:00 AM, Wednesday, 28 May 1952, in the W-Division Conference Room. Those present were:

G. Bell	R. M. Landshoff
H. A. Bethe	C. L. Longmire
A. A. Broyles	J. C. Mark, Chairman
J. W. Calkin	H. L. Mayer
C. Evans	N. Metropolis
F. Evans	L. W. Nordheim
B. E. Freeman	J. C. Potts
R. W. Goranson	F. Reines
G. M. Grover	M. Rosenbluth
M. G. Holloway	S. M. Ulam
F. C. Hoyt	G. M. Wing

E. J. Zadina

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Topics

2. Status of Machine Calculations.

3. [redacted]

4. [redacted] DOE b(3)

5. Experiment to determine Mixing.

6. [redacted] DOE b(3)

2. Status of Machine Calculations.

The Matterhorn ignition burning calculation coded for UNIVAC is not yet completed.

The Alarm Clock calculation is being coded by Richtmyer and Nordheim for UNIVAC and will be run this summer.

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June 20, 1952

MINUTES OF THE THIRTY-FIRST MEETING OF THE THEORETICAL MEGATON GROUP

18 June 1952

1. The thirty-first meeting of the TMG convened at 9:00 AM on Wednesday, 18 June 1952, in the W-Division Conference Room. Those present were:

H. A. Bethe	R. A. Houghton
N. E. Bradbury	R. M. Landshoff
A. A. Broyles	R. B. Lazarus
K. M. Case	C. L. Longmire
F. de Hoffmann	J. C. Mark, Chairman
J. J. Devaney	L. W. Nordheim
C. Evans	J. R. Pasta
F. Evans	J. C. Potts
B. E. Freeman	O. W. Rechard
R. L. Garwin	F. Reines
G. Goertzel	J. R. Reitz
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Topics

2. [redacted]
3. [redacted]
4. Alarm Clock Burning Calculations
5. Experiment on Mixing
6. [redacted]

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b6

Goranson reported on some of the results obtained.

Sweeping Image Cameras

The sweeping image cameras were trained, via mirrors, on the spots indicated as A through J in Figure 2. (2-K is Teller light.) The pipe shields for D and I were evacuated and the others were filled with helium. (It will be observed from the two streak pictures that the luminescence in D and I is quenched by outward expansion of the surface whereas the other spots continue bright from the shocked gas.)

Onset of the Teller light is taken as zero time. This is difficult to determine on some of the streaks. The method used, therefore, was to determine this time where possible and adjust according to the survey data, then use the mean of these values as zero time. The survey assumes the spot to be centered in the 6" diameter mirror and thus there exists a large uncertainty which could amount to 10 shakes. Correction for variation in light path length is not more than 1.5 shakes.

It should be noted therefore that the inferences drawn from these observations are also subject to considerable uncertainty.

32nd Meeting of the Theoretical Megaton Group, June 1952: Hans A. Bethe's treatment of of rise of "Taylor instability" as a mechanism for fuel mixing, when the high pressure gas or fluid from x-ray ablation of the surface of a pusher accelerates/compresses a higher-density solid.

This is in essential agreement with the results obtained at LASL (see 30th Minutes).

6. Investigation of Mixing

If a system is accelerated by a series of sharp pulses, does mixing occur? If this were averaged, one would obtain mixing according to the usual formula. Under what conditions would this be justifiable?

Matterhorn has been investigating this problem and finds that recurrent shocks are capable of giving rise to Taylor instability.

Now

$$A = A_0 e^{\alpha t}$$

where A_0 is initial amplitude and

$$\alpha = \frac{1}{\Delta t} \text{ arc cosh } \left[1 + \frac{g}{2\lambda} (\Delta t)^2\right]$$

where Δt is the time interval between pulses.

If the shocks are close together and λ is large the irregularities in the acceleration are not resolved so that one gets the ordinary expression

$$\alpha = \sqrt{g/\lambda} \ .$$

If the shocks are not closely spaced, then

$$\alpha = \frac{1}{\Delta t} \ln \left[g(\Delta t)^2/\lambda\right]$$

so that

$$A = A_0 \left[g(\Delta t)^2/\lambda\right]^n$$

where $n = t/\Delta t$ = number of shocks in time t.

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33rd Meeting of the Theoretical megaton group, 1952: Hans A. Bethe on Taylor instability for fuel mixing in Alarm Clock.

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6. Alarm Clock Implosion Calculations

DOE (3)

7. Report on Alarm Clock Design

Nordheim reported on a preliminary design study of an alarm clock now being carried out by ACF. This tentative design of a deliverable bomb will come within the present Air Force limitations of

weight	< 50,000 lbs.
outside diameter	< 62.5"
length	< 20'

[redacted]

DOE b(3)

8. Calculations Required for Alarm Clock Design

The theoretical problems and calculations for final alarm clock design were outlined and discussed by Bethe.

[redacted]

DOE b(3)

A problem which has been investigated by Bethe is that of growth of small amplitude waves for variable density (as behind the radiation front). Long waves are unaffected; for short waves k in the expression

$$e^{\sqrt{gk}\cdot t}$$

DOE b(3)

However, the last figure should be tied down by more study of the effect.

6. Alarm Clock Implosion Calculations

34th Meeting of the Theoretical Megaton Group, July 1952: planned testing of GANEX and TANEX diagnostics at a1953 Nevada based Upshot-Knothole tests, prior to Operation Castle (planned for 1954).

DOE b(3)

The density distribution in this case was obtained from mocking-up SEAC runs.

DOE b(3)

1

[redacted]

DOE
b(3)

7. Wall Thickness

Bethe developed a simple formula for the time t_B it takes the Taylor instability to cause a break in terms of the time t_s it takes a shock to traverse the wall.

[redacted]

DOE
b(3)

8. Experimental Program for Upshot (Nevada Spring '53)

8.1 [redacted]

DOE
b(3)

(a) Radiochemistry.

[redacted]

DOE
b(3)

(b) Nuclear emulsion plates as at Greenhouse.

[redacted]

DOE
b(3)

(d) GANEX. Ogle pointed out that it involves a large effort and should be undertaken only if the time dependence of the reaction was of great interest.

(e) TENEX. Bethe considered temperature more interesting than time.

[redacted]

[redacted]

DOE b(3)

There was no specific discussion on these. General points brought up were: It is necessary to keep the total yield of each test below 40 KT. There is a need for radiation flow calculations to decide dimensions. [redacted] DOE b(3)

It was mentioned that there are some worries about a delay in the availability of Li^6 in time for Castle [redacted] DOE b(3)

Rolf Landshoff

Rolf Landshoff

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The contents pages of this pre-Castle handbook summarize results data from the Ivy-Mike test of 1952.

A HANDBOOK

for

OPERATION CASTLE

[redacted] 263 [redacted]

[redacted]

The Pogo Staff

of

J Division

LOS ALAMOS SCIENTIFIC LABORATORY

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Los Alamos, New Mexico

1 January 1954

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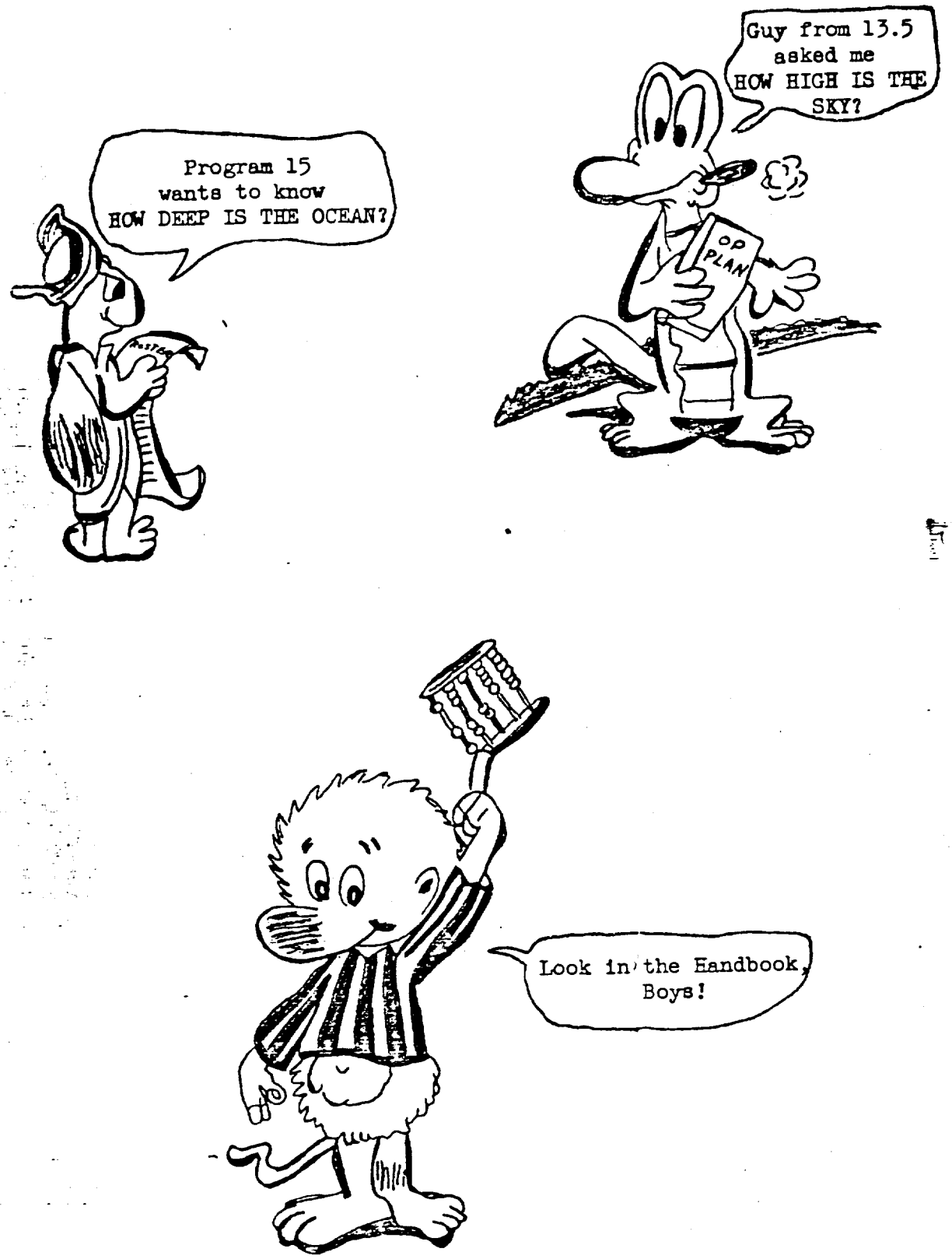
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[redacted]

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3.11 Ivy Mike Fall-out Intensity vs Time 3-14
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3.13 Contamination from Mike Shot, M + 1 Day 3-16
3.14 Contamination from Mike Shot, M + 2 Days 3-17
3.15 Contamination from Mike Shot, M + 3 Days 3-18
3.16 Contamination from Mike Shot, M + 4 Days 3-19
3.17 Contamination from Mike Shot, M + 5 Days 3-20
3.18 Contamination from Mike Shot, M + 6 Days 3-21
3.19 Contamination from Mike Shot, M + 7 Days 3-22
3.20 Contamination from Mike Shot, M + 8 Days 3-23
3.21 Contamination from Mike Shot, M + 9 Days 3-24
3.22 Contamination from Mike Shot, M + 10 Days 3-25
3.23 Contamination from Mike Shot, M + 11 Days 3-26
3.24 Contamination from Mike Shot, M + 13 Days 3-26

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LANL, J-Div.

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SECRET UNCLASSIFIED

SAND88–0868

Relative Effectiveness of a Shallow Earth-Penetrating Nuclear Weapon (U)

Archie V. Farnsworth, Jr.

Computational Physics and Mechanics Division II
Sandia National Laboratories

RESTRICTED DATA

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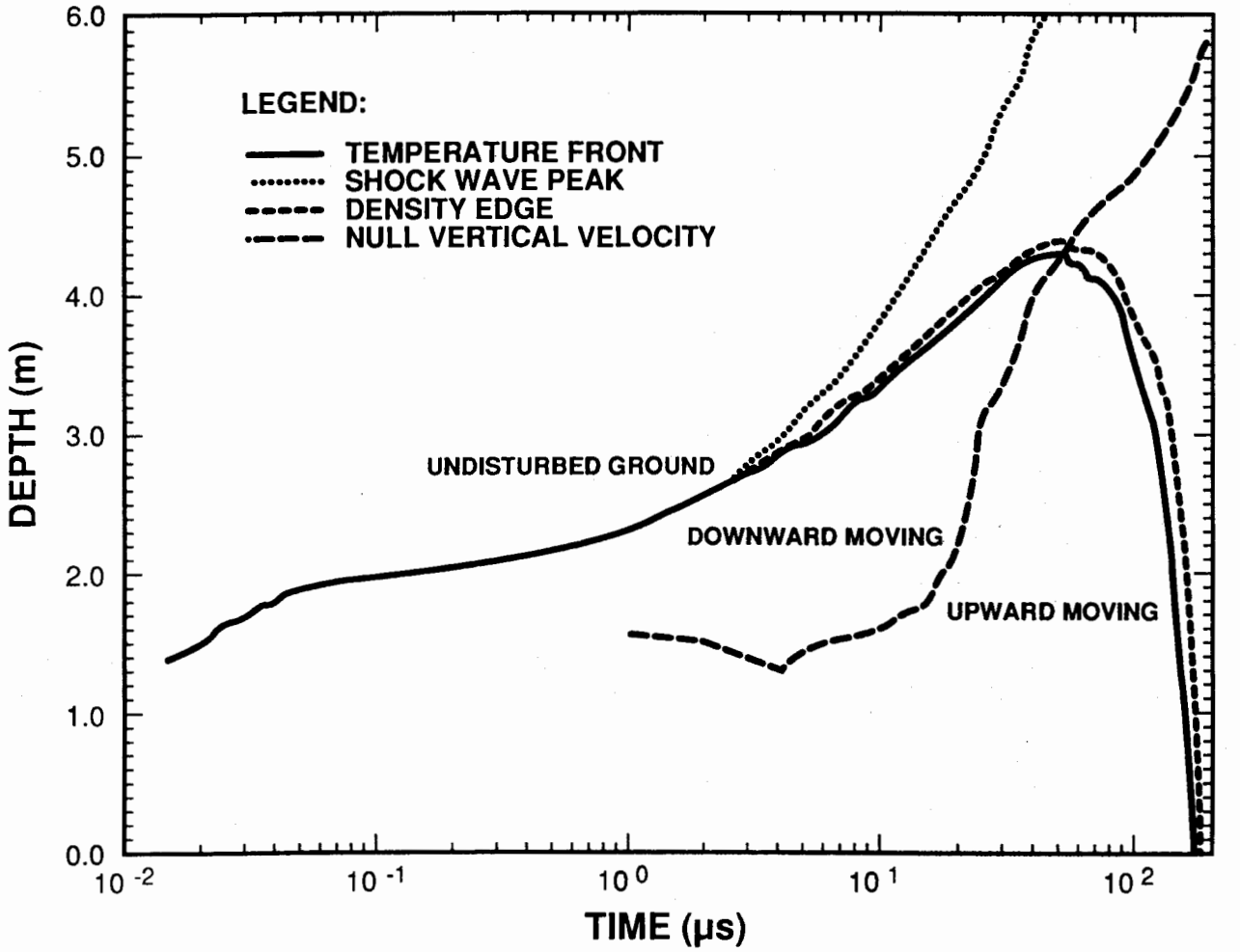


Figure 17: Depth vs. time diagram for phenomenologic features down axis.

[redacted] During this same time interval, the air shock continues to expand under the influence of the warm ejected tuff. The pressure (left) and temperature (right) contours as well as the material interfaces of Figures 19 and 20 show the structure of the above surface phenomena.

[redacted]

In Figure 24, the airblast peak pressure attenuation with range, at several heights, is compared with a reference airblast attenuation curve for a slightly above surface (contact) burst of 250 kT, due to Brode[12]. The lack of smoothness seen in the curves for this calculation results from the late time ejection of higher density, lower temperature, aggregations of tuff, that pass through regions of the grid out of pressure equilibrium

with the surrounding air. The overall comparison with the Brode reference curve, however, is rather good, and suggests that this shallow burst provides essentially half of its energy in airblast effects. It must be remembered, however, that the Brode curve describes an airblast that is driven by the prompt deposition of energy, almost entirely delivered by radiation, at very early time, whereas in the present calculation the energy reaches the atmosphere over a very much longer period of time, largely through the work done by the expansion of heated tuff.

Contours of maximum vertical stress in the ground for this calculation are shown in Figure 25. These contours represent the regions within which all points were subjected to at least the levels of vertical stress noted. The contour quantities are time independent, although they are displayed against the background of a dot density plot of mass density at 0.2 seconds, the concluding time of the calculation. Peak horizontal stresses, peak vertical velocities and peak horizontal velocities are similarly displayed in Figures 26-28, respectively.

DOE
b(3)
+
b(1)
1.5(e):X2

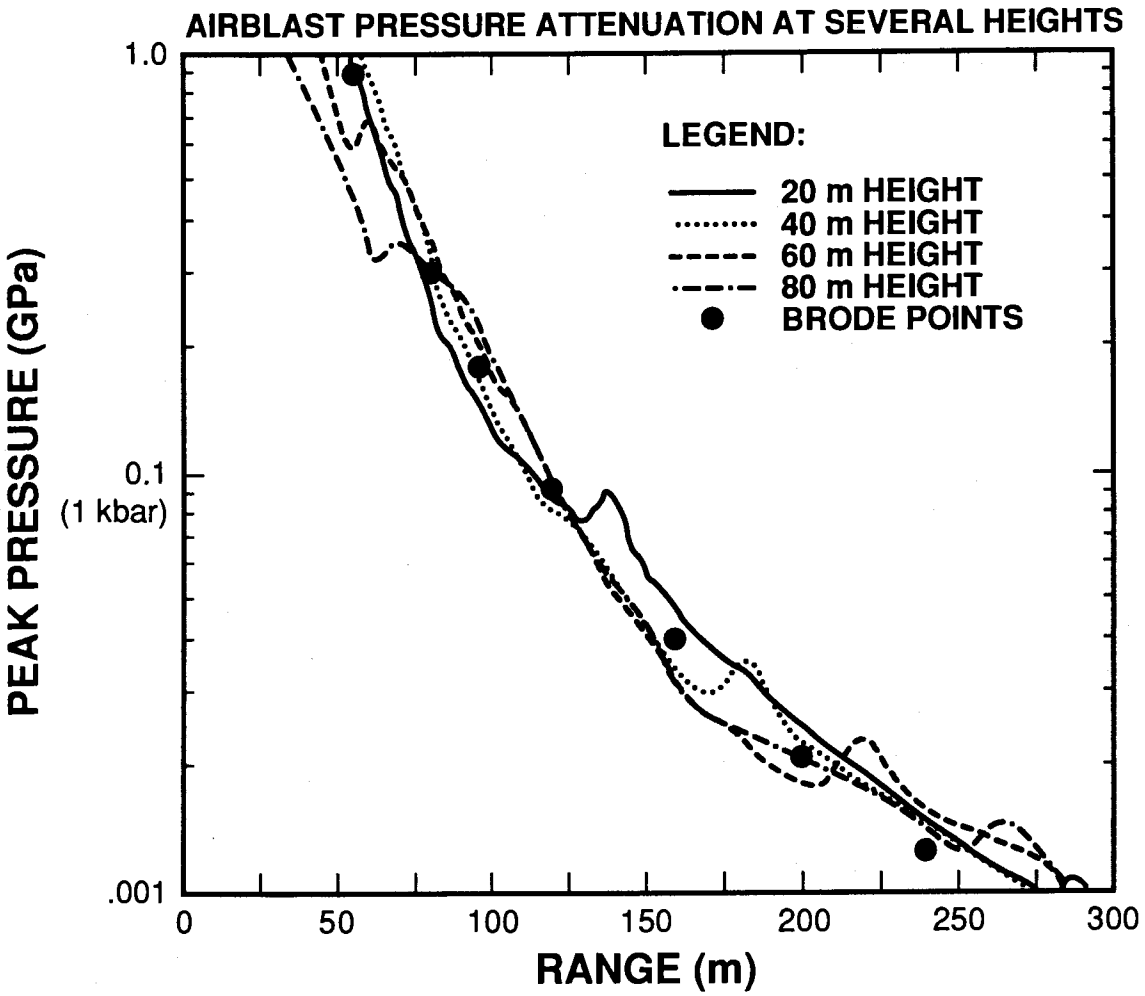
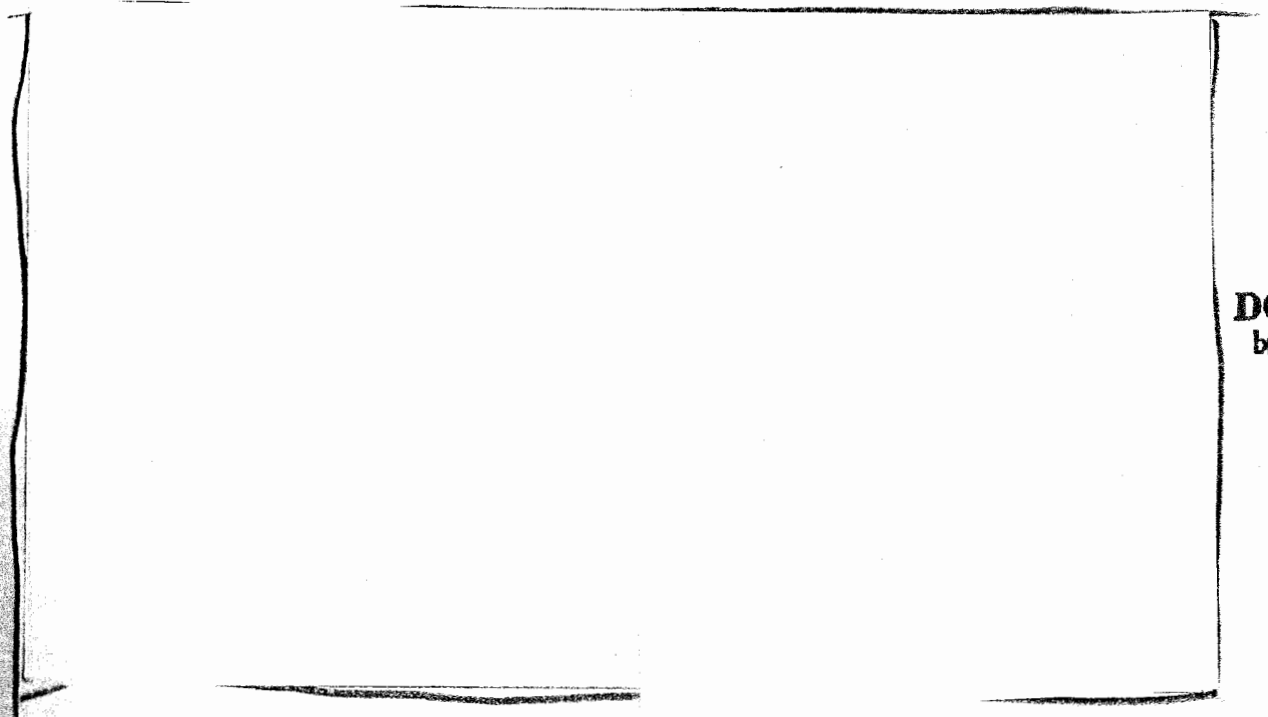


Figure 24: Airblast pressure attenuation with range, at several heights, compared with the Brode airblast results for a 250 kT burst slightly above the surface.

7 Energy Coupling: Discussion and Comparisons

In comparing weapon effects calculations, there is frequently a need to reduce the comparison to a simple, single parameter that can be used as a figure of merit, spanning a wide variety of possible conditions. One such parameter is that expressed by the frequently used concept of "equivalent yield"[15], by which is usually meant the yield at which a chosen reference explosion and environment produces a result that is, in some sense, the same as that for the subject explosion and environment. Obviously, such a simple concept for comparisons will not be satisfactory for every need, but its utility for some purposes makes it quite compelling. Associated with this concept is that of the "yield factor", which can be defined as the ratio of two equivalent yields. We consider here some of the possible yield factors obtainable from the series of calculations recently completed at Sandia National Laboratories, to quantify the effect of height or depth of burst on ground shock. In doing so, we shall utilize the well known scaling rules[16] for explosion effects in which distance and time are scaled by the cube root of the input energy, and other parameters are scaled according to their units, taking energy, time, and length units as fundamental.



DOE
b(3)

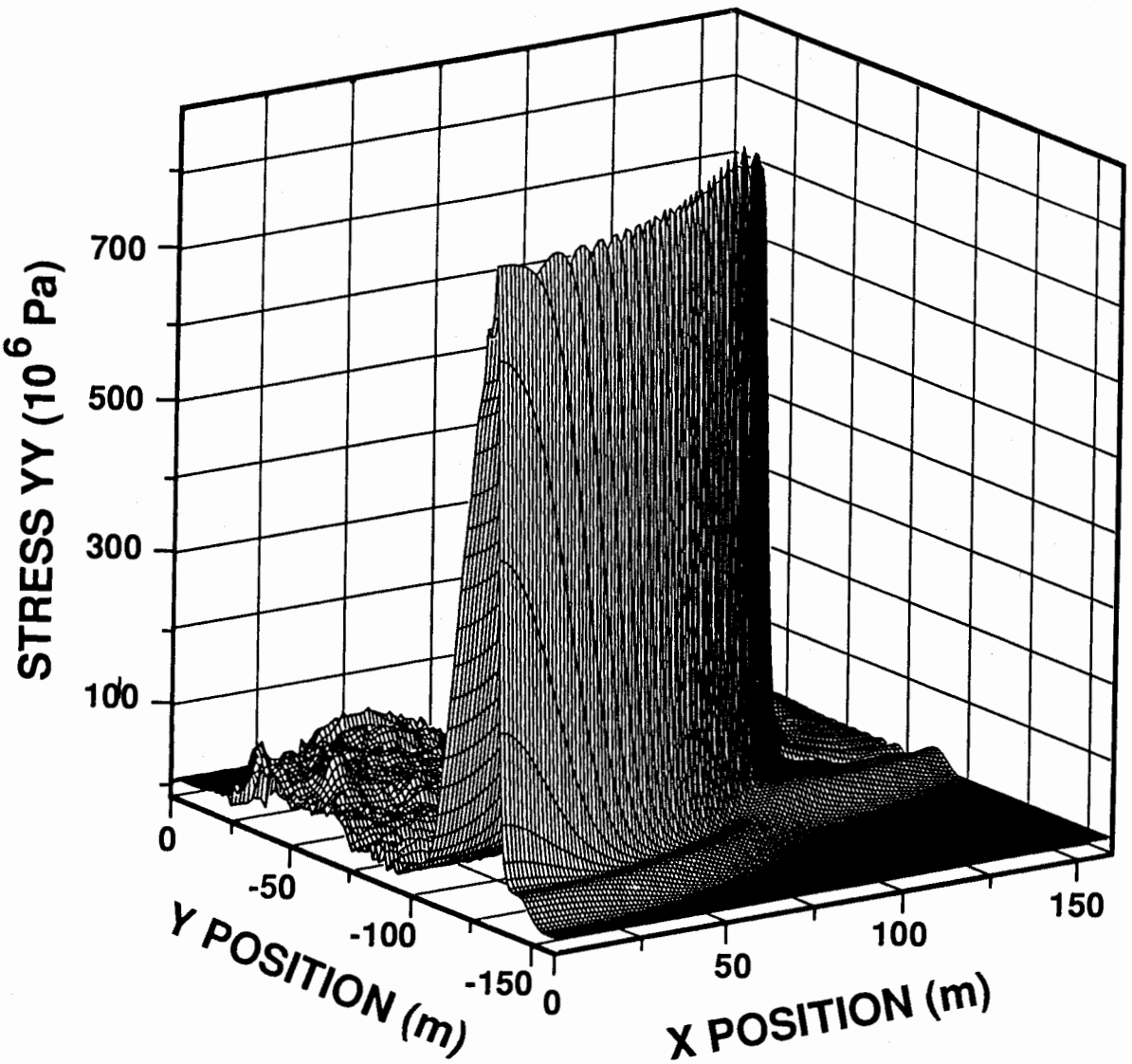


Figure 48: Pressure profile of the shallow burst calculation at 40 ms. The pulse representing the elastic precursor is seen slightly below the main shock wave. Slightly to the right, the airblast wave can be seen.

13. Memo, W. T. Brown to P. Yarrington, *"Spherically Symmetric Explosion in Tuff,"* Sandia National Laboratories, Albuquerque, NM, dated 8/11/87.

14. Steven Peyton, *"Coupling Predictions"*, SSS-R-87-8607, presented at DNA, meeting on Ground Shock Calculations for Strategic Applications, R & Associates, Marina del Rey, CA, 3/19/87.

15. R. E. Crawford, C. J. Higgins, and E. H. Bultmann, "The Air Force Manual for Design and Analysis of Hardened Structures," AFWL-TR-74-102, Air Force Weapons Laboratory, Kirtland Air Force Base, N. M., 10/74, p. 266.

16. Samuel Glasstone and Philip J. Dolan, *"The Effects of Nuclear Weapons, 3rd Ed."* U. S. Gov. Printing Office, Wash. D. C., 1977, p. 100.

APPENDIX 1. Sensitivities to Modeling Assumptions

In connection with the shallow burst study discussed in the text, a number of calculations were performed to test early time sensitivities to changes in the initial conditions assumed. The computing times for running LASNEX using the implicit Monte-Carlo radiation transport method were long ($\approx$ 50 - 100 cpu hours), so most of these sensitivity checks were performed using the much faster diffusion options, especially the three temperature single group diffusion model. The interest here was primarily in determining the effect of different assumptions on the prompt radiative energy loss to the atmosphere. In every case tested, the diffusion treatments of radiation in the ground and debris in the hole led to larger estimates of radiation energy loss than the IMC treatment gave, which does not seem surprising, when one considers the limits inherent in the diffusion treatment.

The parameters varied in these calculations were, primarily, (a) the radiation transport approximation employed, (b) the density and opacity of the debris filling the hole, (c) the diameter of the hole, (d) the depth of the hole, and various combinations of these that the writer deemed interesting. The goal of these calculations was to investigate radiative energy loss sensitivities, rather than to provide a systematic study of the effects of parameter variation; however, the work hopefully provides some modest insights in that direction.

DOE b(3) 5 5(1)

APPENDIX 3. Input to the CSQGEN and CSQ Codes

The CSQ calculation was performed in ten runs, each having two input sets, the first to the CSQGEN program, the second to CSQ. The following are the input for those runs. The versions of those programs were: CSQGEN version 3.0, dated 9 Nov. 1986, and CSQ version 3.0, dated 9 Nov. 1986. The modifications to CSQ used for this work are discussed in References 1 and 2.

Input for CSQGEN, run 1.

DOE
b(1)

APPENDIX 4. Additional Information and Plots

A few figures not included in the text are presented here, for the use of those interested in additional detail on the evolution of the ground shock with time or some other features of the calculation. The first two figures, A1 and A2, provide early time density, temperature, and velocity profiles as a function of horizontal range, starting from the center of the burst (1.13m below the ground surface). The next seven figures provide density, temperature and pressure profiles vs. depth on axis, at each decade in time from 10^{-7}s to 10^{-1}s. The next four figures provide time histories of the maximum principles stress off axis, at a range of 400m, and depths at 100m intervals. Finally, Figure A14 provides a log-log version of the depth vs. time plot of Figure 17 of the text.

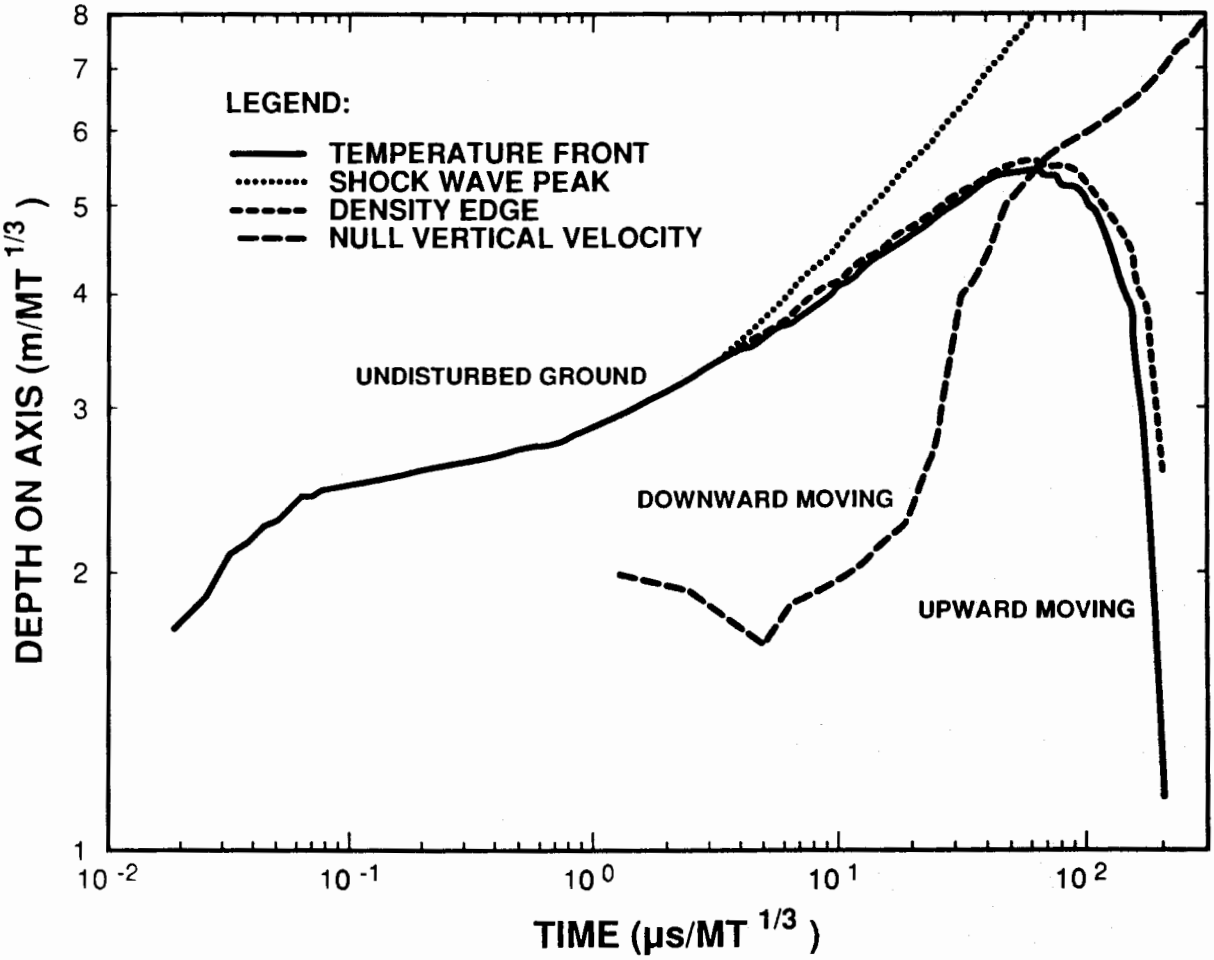


Figure A13. Plot of depth vs. time for some significant features down axis.

APPENDIX 5. Airblast: An Unsettled Issue

An intriguing feature of the airblast attenuation with range plot of Figure 14 of the text is that the rate of attenuation with range appears, on the average, to be somewhat less than that of the reduced-yield above-surface burst, as seen by the fact that at high pressures the present calculated curves lie slightly

below the Brode points while at low pressures they seem to lie slightly above the corresponding points. This feature appears to have its origin in the previously noted phenomenological difference with the above surface burst airblast: the large quantity of ground ejecta driving the airblast, in the shallow buried case.

An above-surface burst exhibits an impulsive delivery of most of the airblast energy by radiation, which forms the familiar fireball from which a shock wave subsequently emerges. In the present case, most of the energy is delivered over a much longer time interval, by the $\int pdv$ work performed on the atmosphere by the expanding column of ground ejecta. This quasi-cylindrical push against the atmosphere may result in a less rapidly attenuating shock front. The airblast from the Baker event (relatively shallow burial in ocean water) has been reported[1] to have produced a reduced attenuation rate at low pressures. Goertner[2] has suggested that the origin of the reported reduced attenuation rate might be the 2-D aspect of the air shock wave, as it develops, quasi-cylindrically, under the influence of an expanding column of water. This phenomenon could take on considerable significance in the context of aircraft delivered systems, for aircraft safety. The issue can not, at this time, be said to be resolved on the basis of either theoretical understanding, which does not clearly support the claim so far as this author has determined, or by the Baker data itself, which shows considerable scatter, and could be subject to alternative explanations.

---

[1] Norma O. Holland, *"Airblast from Underwater Nuclear Bursts (U),"* NOLTR 70-115, Naval Surface Weapon Center, White Oak, Md., 7/70.

[2] John F. Goertner, private communication with the author.

[redacted]
UNCLASSIFIED

EARTH PENETRATOR WEAPON SYSTEM DESIGN

W. J. PATTERSON AND N. A. LAPETINA; SANDIA NATIONAL LABORATORIES

INTRODUCTION

MAJOR EPW SUBSYSTEMS

EPW SYSTEM DESIGN RATIONALE

TEST PROGRAM

WEIGHT REDUCTION



WJP/5165/3–88

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[redacted]

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MAJOR EPW SUBSYSTEMS

EPW CASE

NUCLEAR SYSTEM

WARHEAD ELECTRICAL SYSTEM



WJP/5165/3-88

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CONFIDENTIAL

EPW SYSTEM DESIGN RATIONALE

REQUIRED INFORMATION FOR FIRST DESIGN ITERATION

EPW CASE DESIGN

- TERRADYNAMIC CONSIDERATIONS
- TARGET CHARACTERISTICS THAT IMPACT EPW SURVIVABILITY

NUCLEAR SYSTEM LOCATIONS

WARHEAD ELECTRICAL SYSTEM CONCERNS



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UNCLASSIFIED

REQUIRED INFORMATION FOR FIRST DESIGN ITERATION

TARGET SET DEFINITION

LOCATION, DEPTH, SIZE AND HARDNESS OF STRUCTURES

SITE GEOLOGY, SOIL AND ROCK MATERIAL PROPERTIES, TOPOLOGY,

POTENTIAL DELIVERY SYSTEMS

ICBM, CRUISE MISSILE, OR GRAVITY BOMB

ESTIMATE OF NUCLEAR YIELD REQUIRED TO DESTROY TARGETS



WJP/5165/3-88

UNCLASSIFIED

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EARTH PENETRATOR WEAPON SYSTEM DESIGN

EPW CASE DESIGN CONSIDERATIONS

INTERNAL CASE SIZING

DIMENSIONS DEPENDENT ON NUCLEAR SYSTEM AND WARHEAD ELECTRICAL SYSTEM (WES) DESIGNS

EXTERNAL CASE SIZING

DIMENSIONS OPTIMIZED FOR MINIMUM LENGTH, DIAMETER AND WEIGHT BUT MUST CONSIDER:

- TERRADYNAMIC STABILITY
- WORST CASE STRUCTURAL LOADING
- DELIVERY SYSTEM ACHIEVABLE IMPACT CONDITIONS

CASE MATERIAL

HIGH STRENGTH STEEL WITH HIGH FRACTURE TOUGHNESS



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TERRADYNAMIC CONSIDERATIONS

EPW STABILITY STRONGLY INFLUENCED BY:

EPW STRUCTURAL LOADING PRIMARILY INFLUENCED BY:

- NOSE SHAPE (SHARPER NOSED EPW RESULTS IN LOWER LOADS)
- WEIGHT TO CROSS SECTIONAL RATIO, W/A

STABILITY AND STRUCTURAL LOADING ALSO STRONGLY DEPENDENT ON:

- TARGET PROPERTIES
- SURFACE FEATURES
- IMPACT CONDITIONS



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TARGET CHARACTERISTICS THAT IMPACT EPW SURVIVABILITY

HARDNESS

- CONFINED SHEAR STRENGTH (PRESSURE DEPENDENT)
- VOLUMETRIC COMPRESSIBILITY
- DENSITY
- MOISTURE CONTENT

IRREGULARITIES (INDUCE LARGE LATERAL LOADS)

- BUILDINGS
- RUBBLE
- BOULDERS
- TREES
- TARGET NON HOMOGENEITY



NAL/8152/3-88

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EARTH PENETRATOR WEAPON SYSTEM DESIGN

WARHEAD ELECTRICAL SYSTEM DRIVERS

NUCLEAR SAFETY

DELIVERY SYSTEM INTERFACE

RUGGED, RELIABLE, FLEXIBLE PACKAGING

MULTIPLE FUZING OPTIONS

AIRBURST, CONTACT, AFTER PENETRATION, SYNCHRONOUS



WJP/5165/3-88

TEST PROGRAM

TEST PROGRAM OBJECTIVES

DEMONSTRATE STRUCTURAL INTEGRITY

DEMONSTRATE STABILITY OF PENETRATOR DESIGN

PROVIDE STRAIN AND ACCELERATION DATA FOR CODE VERIFICATION

EVALUATE EFFECTIVENESS OF COUNTERMEASURES

EVALUATE NEW EPW CASE MATERIALS

DEMONSTRATE FUNCTIONAL CAPABILITY OF WES COMPONENTS



NAL/8152/3-88

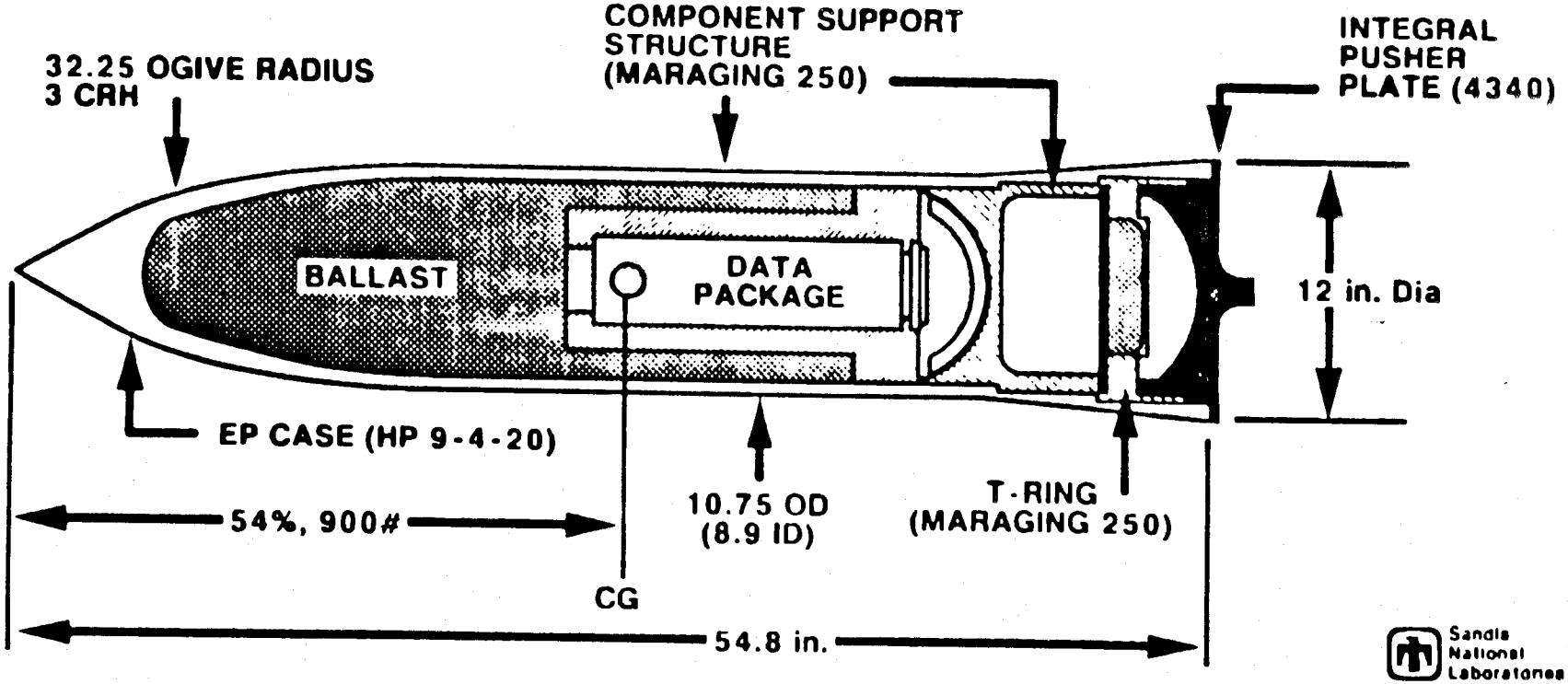
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EARTH PENETRATOR TEST DEVICE

PROPERTIES

L/D = 5.1
W/A = 9.9
Wt = 900 lb
CG = 29.6 in.
PITCH = 2.1×10^5 lb-in.^{2}



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SAB2001323400000

Tunnel Damage from Ground Shock (U)

Jon Rogers
Dept. 5412

June, 1997

M Buhmeld 10/23/00

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
1ST REVIEW DATE: 12/3/99 DETERMINATION (CIRCLE NUMBER(S))
AUTHORITY: DC DD
NAME:
1. CLASSIFICATION RETAINED
2. CLASSIFICATION CHANGED TO:
3. CONTAINS NO DOE CLASSIFIED INFO
2ND REVIEW DATE: 12/8/99
AUTHORITY: DD
NAME:
4. COORDINATE WITH: DOD
5. CLASSIFICATION CANCELED
6. CLASSIFIED INFO BRACKETED
7. OTHER (SPECIFY): DoE ltr dtd 6 Feb 97
(DOE info in black)

Formerly Restricted Data
Unauthorized disclosure subject to Administrative and Criminal Sanctions. Handle as Restricted Data in Foreign Dissemination Section 144.b, Atomic Energy Act of 1954.
Classified by A. G. Easterling Org. 5412
Title Evaluate Reinforced Concrete Dat... Date 12/1/97

JDR:5412:6/6/97:tnldmg.ppt

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98SA20B000107

Issue: Hard Target Defeat (U)

- **Briefing Outline**
  - Motivation
  - Previous Analyses
  - Example
  - Areas of Concern
  - Proposed Further Analyses

Why look at Tunnel Vulnerability? (U)

[redacted]

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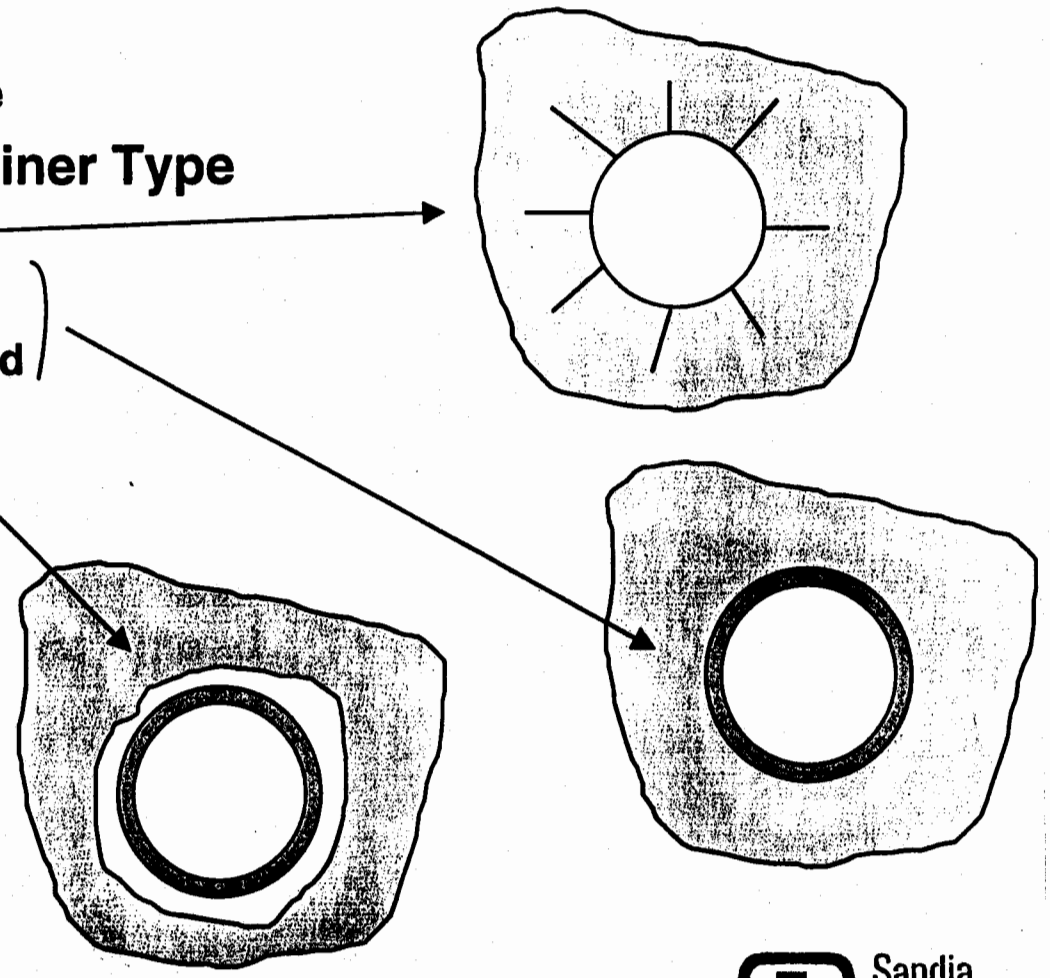
Attack Tunnels Using Nuclear Weapons (U)

DOE
b (3)

Sandia National Laboratories

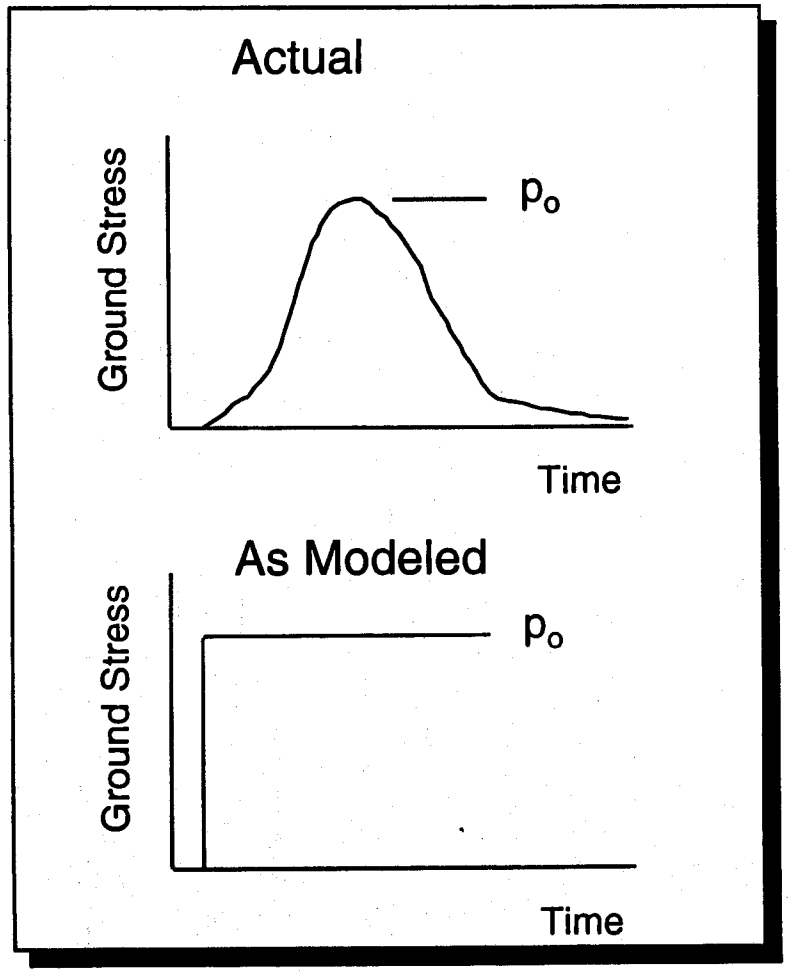
First Define the Tunnel (U)

- **Geology**
  - local to the site
- **Construction/Liner Type**
  - Rockbolted
  - Concrete lined
  - Composite lined
  - Backpacked



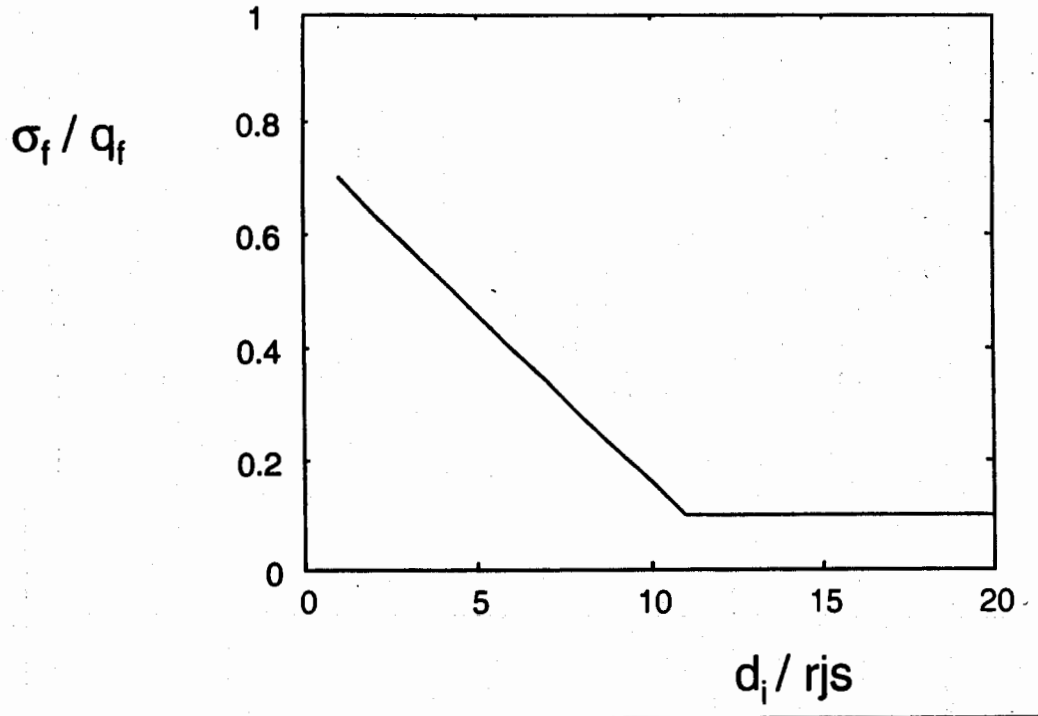
Hendron and Aiyer Analysis (U)

- **Published by Corps of Engineers in 1972**
  - Extension of work by Newmark (1969)
  - These are "Big Names" in Rock Mechanics
- **Assumes static loading**
  - Uniform external pressure, p_o
  - p_o is the maximum ground stress
  - Elastic/Plastic analysis with dilatency
  - Uses Coulomb-Navier failure criteria
- **Calculate Hoop Strain for a given external pressure**



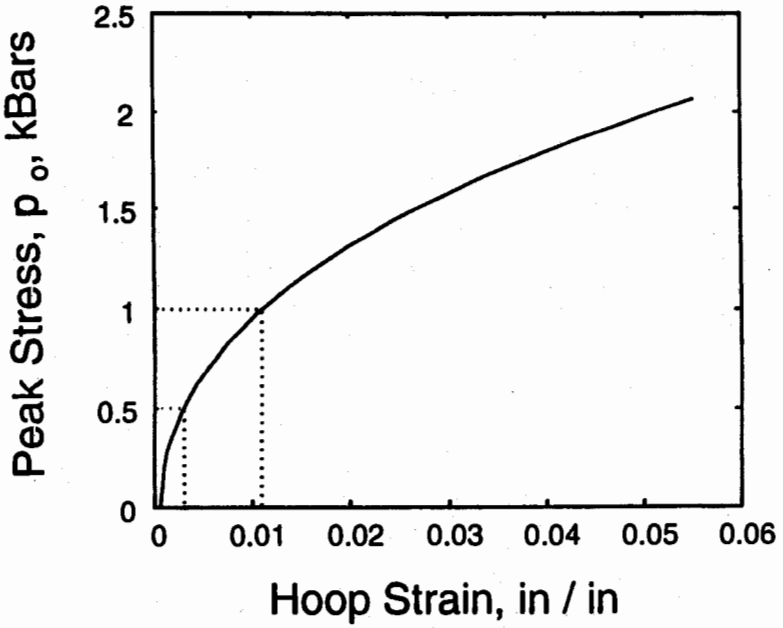
Hendron and Aiyer Analysis - Cont'd (U)

Use a Rock Strength Reduction Factor (SRF)



σ_f = in-situ rock strength
q_f = unconfined laboratory rock strength
rjs = rock joint spacing
d_i = rock opening diameter

Hendron and Aiyer Analysis Results (U)



- Curve Depends on:
  - Liner
  - Rock Properties
  - Tunnel Size
- Similar / Identical sections in different locations have different peak stresses (p_o) but the same curve.
  - Different hoop strains
  - Identify failure/survival strain
- Many issues to consider

Issues to Consider (U)

- **Dynamic loading effects**
  - Rock tends to be a lot stronger under dynamic loads than under static loads
  - Impulse versus peak load analysis
- **Liner/Rock interface not well modeled**
- **Test data come from 2 geologies**
  - Granite
  - Tuff
- **What are the inherent biases of the analysis?**

"Calibration" of Hendron and Aiyer Results (U)

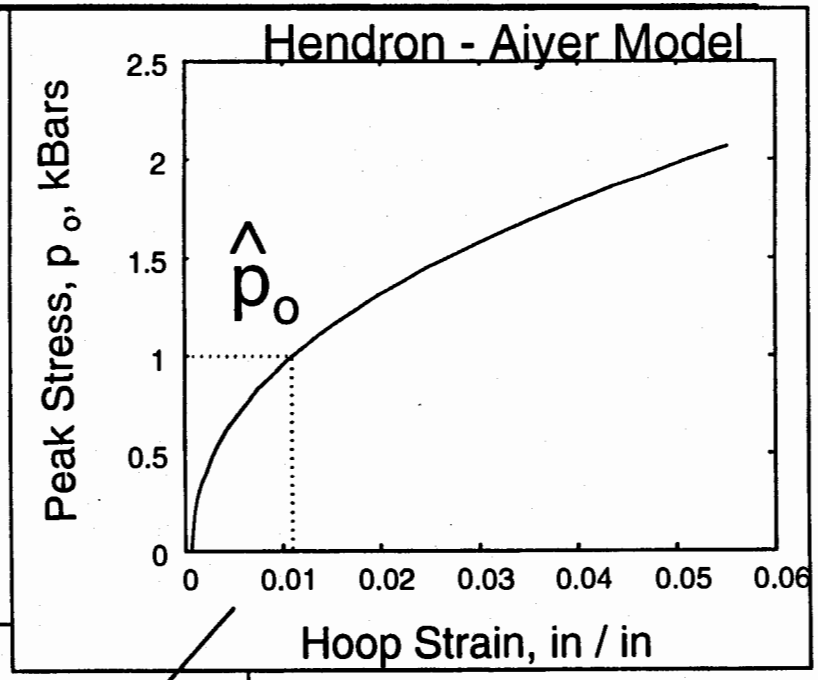
- "Calibrated" for various construction types
  - Much of data from 3 UGTs
    - Piledriver and Hard Hat - tests in Granite
    - Mighty Epic - test in Tuff
  - Lots of tunnel sections and liner types, few large sections
    - Most sections 6 - 7 feet in diameter
    - Most sections loaded side-on
- Work was in support of Deep Basing (1983)
  - Goal was protection of U.S. assets
  - Focus was on "Sure Safe" design
    - Choose to err on the side of "defender conservative"

"Calibration" Continued (U)

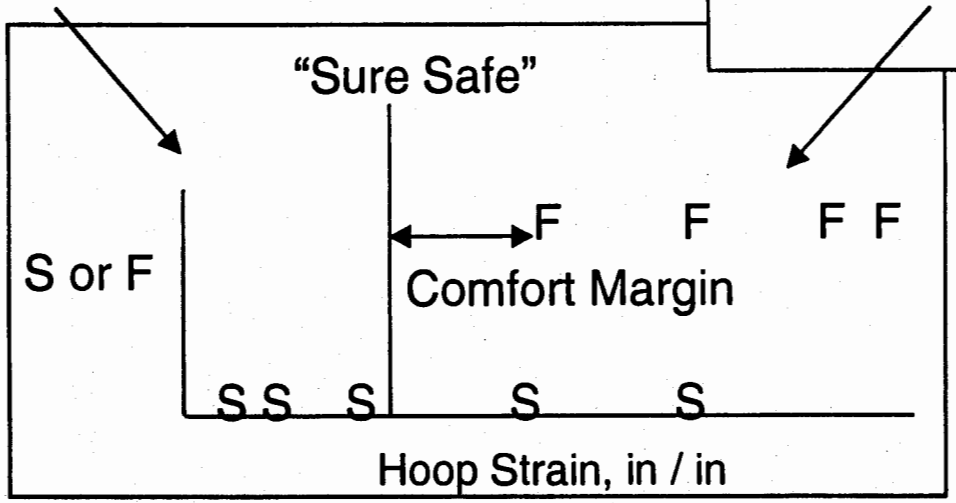
- The project officer made a post-test damage assessment
  - Severe Damage: Requires Remining
  - Moderate Damage: Major Repairs
  - Light Damage: Minor Repairs
  - Undamaged
- These categories were further reduced to
  - Survived
  - Failed

The "Calibration Trail" (U)

{Instrumentation} → $\hat{p}_o$ →



{Survive / Fail Assessment}



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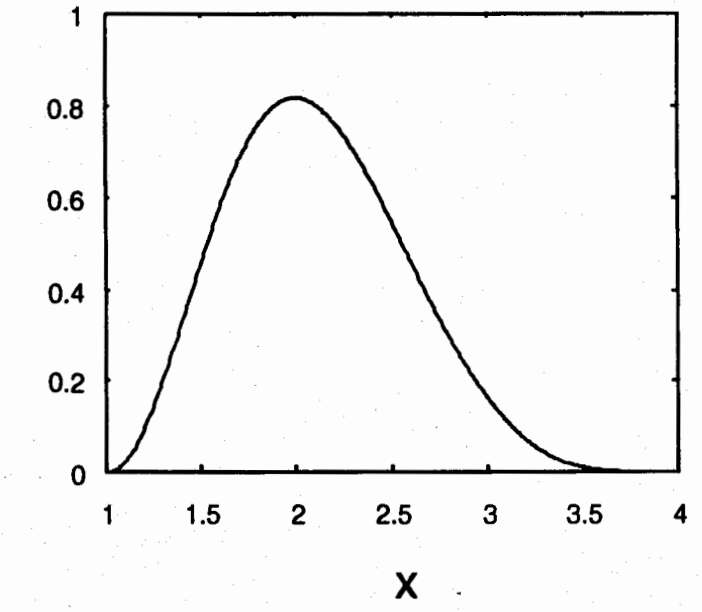
Ground Shock Vulnerability Calculation (U)

- **1990 DIA Report Describes Method**
  - Uses Hendron and Aiyer Method for p_o - hoop strain relationship
  - Converts "Sure Safe" hoop strains to "Failure Strains"
  - Large Monte Carlo simulation representing uncertainty in target parameters
- **Results in a distribution of failure stresses, p_o**
  - Failure values for p_o are fit to a Beta-distribution
  - Published tables give min, max, mode, and t-value
  - These values are used for GVN determination
    - See later chart for more details
  - GVNs are used in PDCALC 6.2

What is the Beta distribution? (U)

- **The Beta distribution has several convenient characteristics.**
  - **Bounded**
  - **Can take on almost any shape**
  - **Described by 4 parameters**
    - **minimum value**
    - **maximum value**
    - **mode**
    - **t - peakedness**
- **Uniform distribution**
  - **t = 2**

Beta distributed variable, x
min = 1, max = 4, mode = 2, t = 9



Calculating Tunnel Vulnerability (U)

- Select minimum and maximum values for all important parameters, for the target of interest
  - Geological characteristics
  - Liner characteristics
  - Size
  - "Sure Safe" strains (from earlier table)
- Select Beta distribution characteristics for each parameter
  - Peakedness, (t), and mode
- Run Monte Carlo simulation
  - Example has 10,000 draws from 13 distributions

Observations and Issues (U)

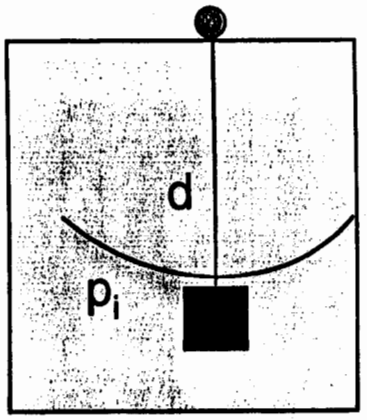
- The distributions represent uncertainty about the site parameters, not within site variability
  - E.g., Sure safe hoop strain
    - Assumed Beta Distribution ranges from:
      - 0.004 to 0.025 (Unreinforced concrete to very heavily reinforced)
      - The tunnel liner itself does not vary
- Choosing the resulting p_o mode is approximately the same as running a nominal case analysis - uncertainty is nearly irrelevant
- Uncertainty distributions have weak supporting rationale
  - Ranges, peakedness, independence

Hendron and Aiyer Analysis Issues (U)

- **Hendron and Aiyer Method assumes static loads**
  - Rock is much stronger under dynamic loads than static loads - strain rate effects
    - Tunnel is stronger than static load predicts
    - Conservative assumption for tunnel designer
  - Requires full engulfment of structure in ground shock wave
    - Probably OK for nuclear - not even close for conventional weapons effects
  - When failure occurs - loading or unloading - may be important but is not included in analysis

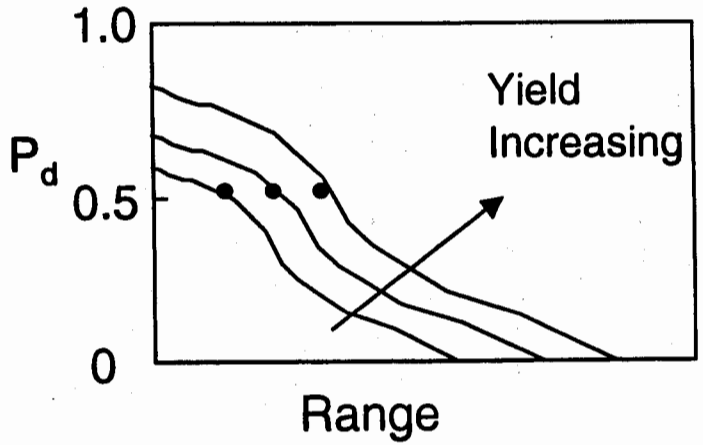
Where do GVNs come from? (2) (U)

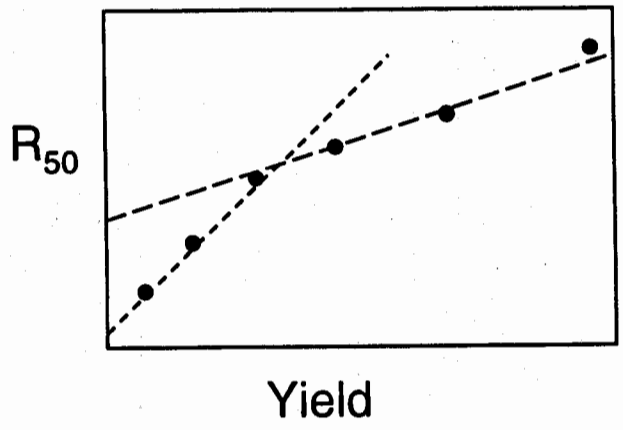
- **Step 3: Pick many weapon yields**
  - Evenly spaced on log scale from min to max
  - HOB is 0.5 meters
- **Step 4: Monte Carlo simulation drawing from distributions on:**
  - Facility depth (assumes weapon directly above facility)
  - Geology parameters
  - Result: p_i, the peak ground stress at the facility
  - Compare to the chart in Step 2 to get P_d for that trial
  - Save P_d and depth for that trial associated with the yield.



Where do GVNs come from? (3) (U)

- **Step 5: Repeat the process for many yields**
  - Fit P_d vs. Range to lognormal for each yield
  - Select R_{50} for each yield from fitted curve





- **Step 6: Fit 2 straight lines to 50 % P_d values**
  - Determine GVN (parameters of curve fit)

Further Analyses of Tunnel Vulnerability (U)

- **Review tunnel vulnerability assessment methodology**
  - More sophisticated techniques are available
  - Include dynamic loading effects
- **Look again at failure models and test data**
  - Identify where conservatism exists and quantify
  - Reanalyze for "Sure Kill" levels
- **Consider other treatments of uncertainty**
  - Run selected cases
  - Evaluate parameter effects on p_o

CINC Priorities for Counterproliferation Capabilities (U)

CINC Priority	CINC's Counterproliferation Capabilities
1	Detection/characterization of BW/CW Agents
2	Intercept cruise missiles
3	Defeat underground targets
4	Characterize and identify underground targets
5	Collect and analyze intelligence
6	Passive defense enabling operations
7	Support for operations in NBC environment
8	Biological vaccines
9	Planning and targeting for above ground infrastructure
10	BW/CW agent defeat
11	Detection and tracking of shipments
12	Prompt mobile target kill
13	Support for Special Operations Forces
14	Locate, detect, and disarm WMD in CONUS/OCONUS

LDRD Project: Unexplored Penetrator Regime Against Super-Hard Underground Facilities

Part 2: Review of Tech Base Activities

Technical goal

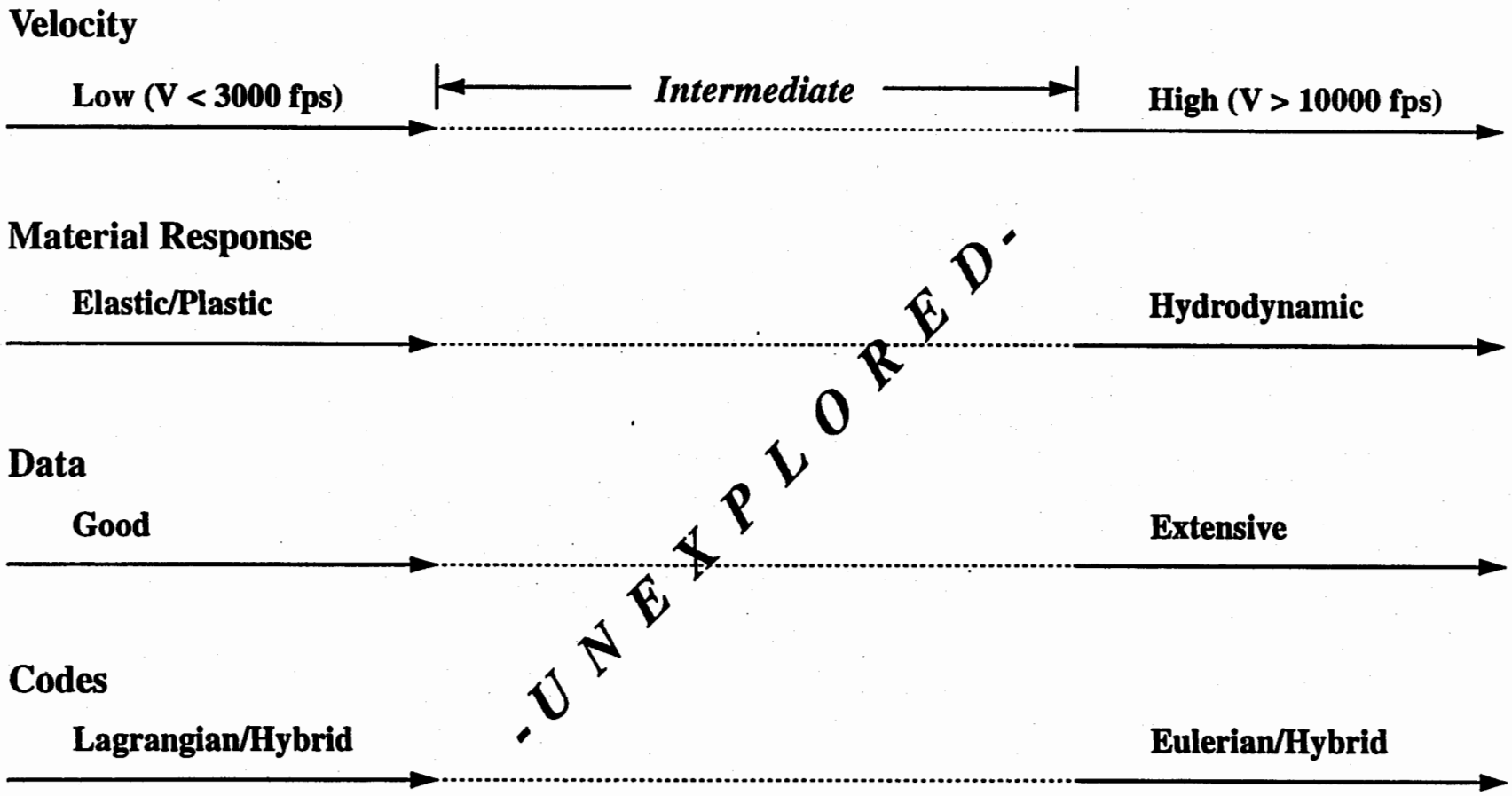
- Develop basic understanding computational models to predict unique features of earth penetration at high velocity:
  - Penetrator abrasion, plastic deformation, and failure

End product is a tool to predict:

- **Survivability:**
  - Predict loads, peak stresses on the penetrator case and warhead.
- **Lethality:**
  - Predict depth of penetration.

EPW LDRD

Modeling Regimes/Capabilities



Technical challenges

- Overcome lack of understanding of physical processes.
  - Abrasion, friction, other interface phenomena.
  - Material failure: cracking, plastic flow.
- Overcome difficulty in modeling interface numerically
  - Allow gross changes in penetrator shape.
  - Develop ability to remove penetrator material from Lagrangian mesh.
  - Predict structural response while the above are occurring.
- Contribute to penetrator design process in this velocity regime.
  - Materials science basis.
  - Computational tools.

Major Technical R&D Activities

- **Physics model development**
  - Metal penetrator wear/erosion/abrasion
- **Micrographic analysis**
  - Investigate/discover erosion phenomenology
  - Guide model development
- **Ballistic testing**
  - Samples for micrographic analysis
  - Validation data for computational models
- **Production code implementation of penetrator erosion model**
  - Platform for validation of computational models
  - Model-based tool for routine EPW engineering design & analysis

Technical accomplishments: Abrasion model

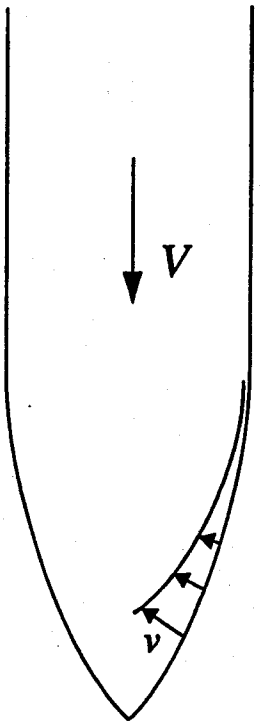
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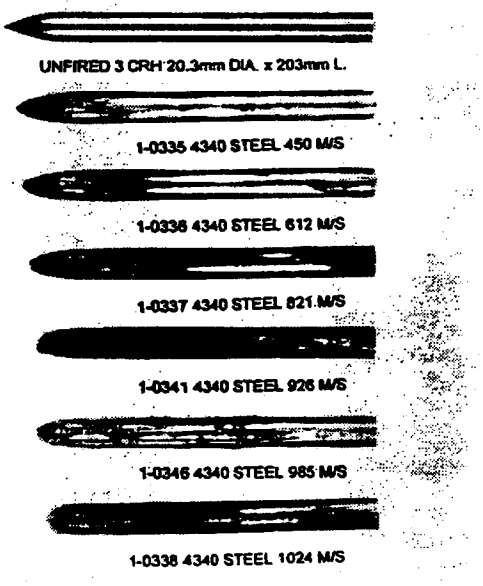
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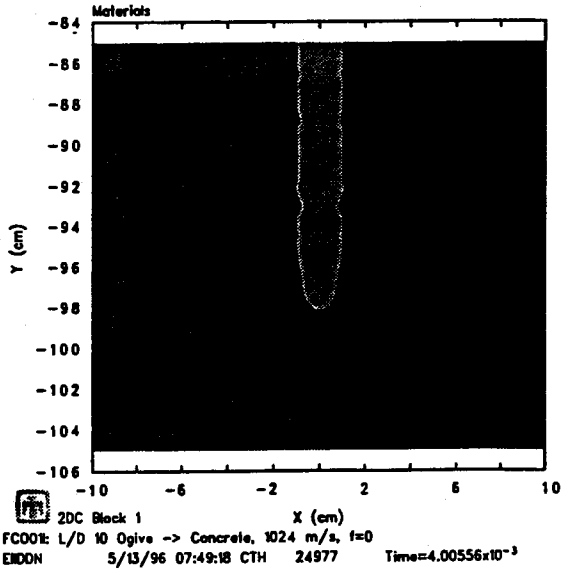
- CTH model removes mass from the surface according to local conditions.
- Data show mass lost is proportional to initial KE. This suggests model shown at right:
- Results agree well with experimental data by Forrestal on mass loss and penetration depth.

$$v = \frac{CVp}{\rho}$$

C=constant

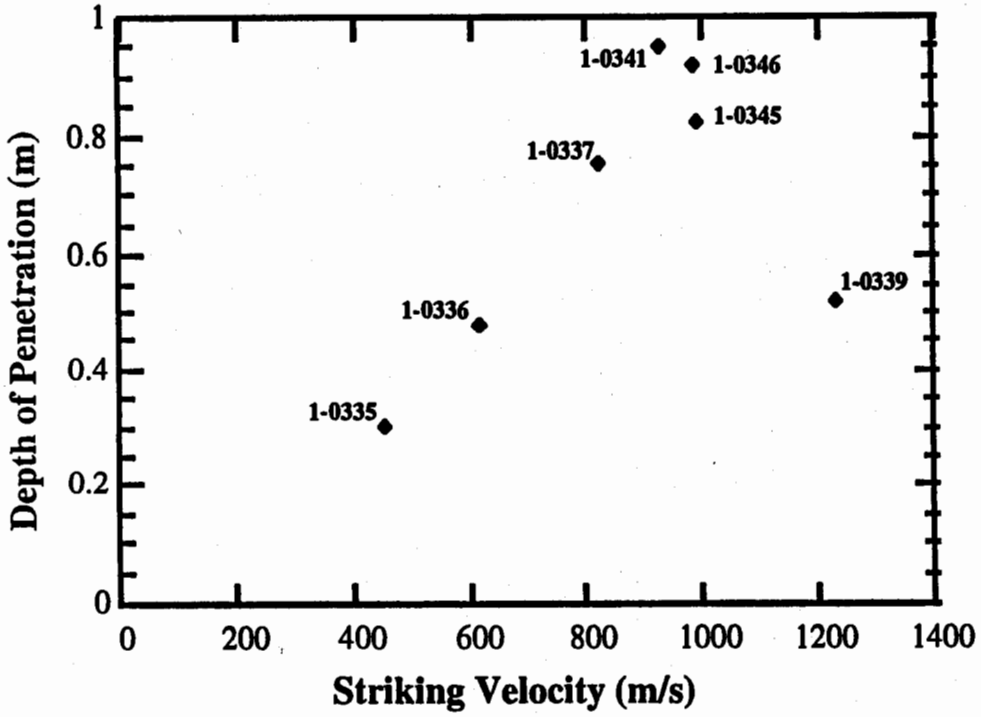


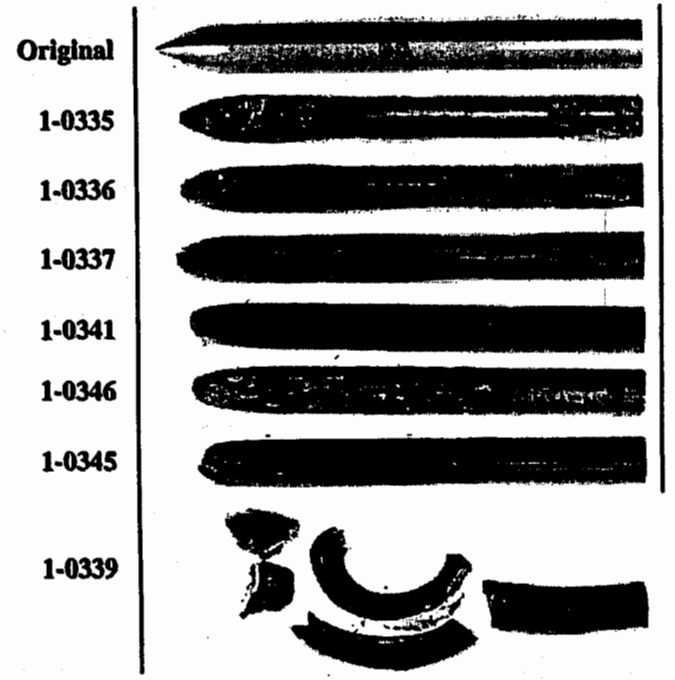




EPW Technology

AISI E4340 SAQ Steel Projectiles into SAC-5 Concrete



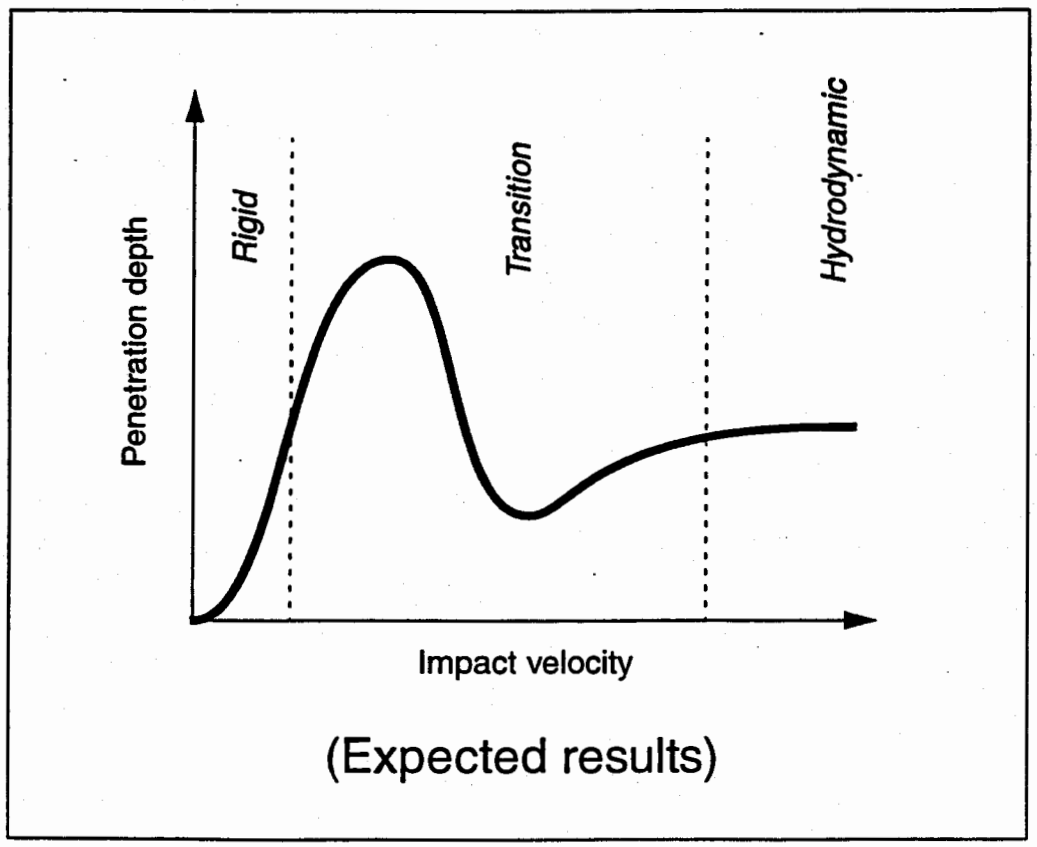


Technical accomplishments: Experimental data up to 3 km/s

Sandia National Laboratories

Computational Physics & Mechanics Department

- Existing data on high velocity penetration is fragmentary.
- Obtain a consistent set of data over a wide range of velocity.
  - Steel rods into aluminum blocks, 1-3 km/s.
  - For use in model validation.
    - ♦ Can we predict the expected maximum and minimum in the penetration depth curve as a function of velocity?
  - To be completed in FY96.



(Expected results)

FY96-97 planned work

- Improve and validate penetrator-target coupling algorithm, implement in ALEGRA.
- Get data for and thoroughly understand penetrator depth curve in transition region (steel -> aluminum).
  - Reproduce computationally.
- Incorporate into models what is learned from micrographic analysis and penetration data.
  - Physical models can be incorporated into any applicable code.

Resource Utilization

FY96	*5400 (Rogers)*	*9200 (Yarrington)*	*2100 (Hansen)*
	186,354	*233,478*	*223,839*
Labor	*165,000*	*164,000*	*150,000*
DC	*9,000 Travel*	*34,000 Contract*	*34,000 Tests*
SC	*0*	*20,000 Computer*	*25,000 Shop*
			($30,000 Kelley)
			($80,000 Forrestal)
FY97	*230,000*	*225,000*	*221,000*
	45K Additional	*same*	*same*
	for test & travel		

LDRD Products - End FY97

1. *SNL/DIA Publication on Hard Target Characterization*
2. *Report on Military Mission Considerations for EPW Use*
3. *Report on Nose-Tip Enhancements for Increased Penetration*
4. *Summary of Scale Model Test Results*
5. *An Abrasion/Erosion Model that can be incorporated in Hybrid Numerical Codes for Penetration Analysis*

SECRET

Response to MAWG Questions

EXISTING NUCLEAR STOCKPILE OPTIONS
VARIABLE YIELD NUCLEAR EPW WEAPON

- **Design Information**
- **Weapons Output Information**
- **Effects/Effectivness**
  - **Fireball Effects**
  - **Groundshock**
  - **Fallout**
- **Collateral Damage**

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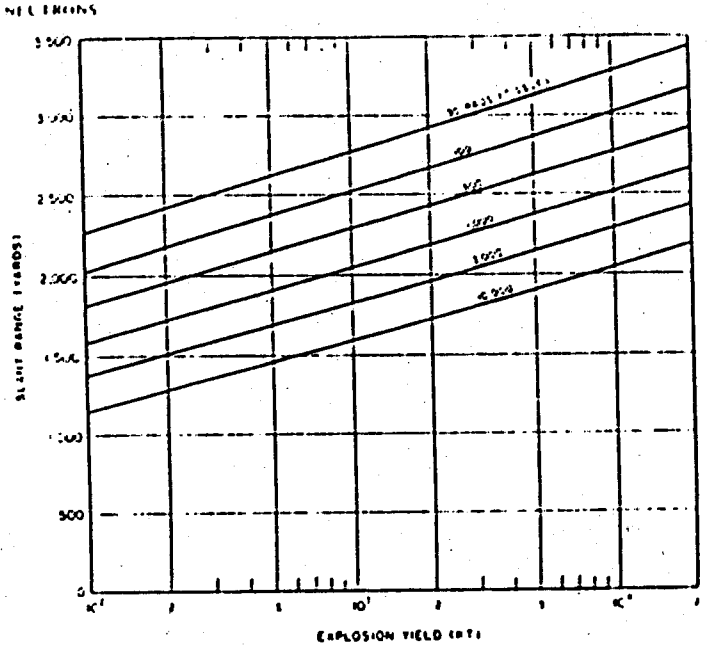
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Fireball Effects/Effectivness

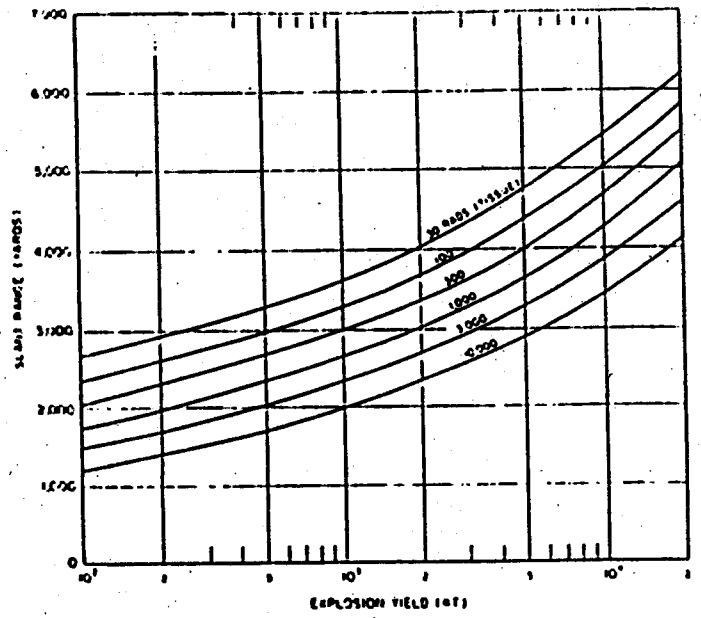
- Within some fraction of the radius of a fireball, all C/B agents will be destroyed
  - Steve Schaefer Presentation
- Proposed Fireball Kill Radius

$$R = 145(kt)^{0.4}$$

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Slant ranges for specified neutron doses for targets near the ground as a function of energy yield of air-burst thermonuclear weapons based on 0.9 sea-level air density (Reliability factor 0.25 to 1.5 for most thermonuclear weapons)



Slant ranges for specified gamma-ray doses for targets near the ground as a function of energy yield of air-burst thermonuclear weapons with 50 percent fission yield, based on 0.9 sea-level air density (Reliability factor from 0.25 to 1.5 for most thermonuclear weapons)

Characteristics of Expected Radiation Field

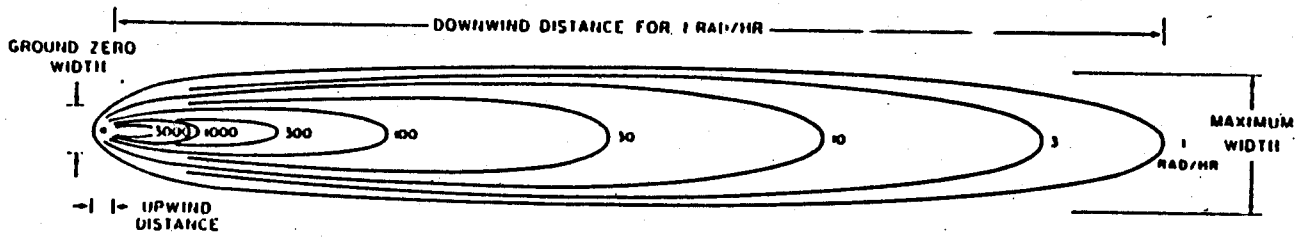


Illustration of idealized unit-time dose-rate pattern for early fallout from a surface burst (The contour dimensions are indicated for a dose rate of 1 rad/hr.)

SCALING RELATIONSHIPS FOR UNIT-TIME REFERENCE DOSE-RATE CONTOURS FOR A CONTACT SURFACE BURST WITH A YIELD OF *W* KILOTONS AND A 15 MPH WIND

Reference dose rate (rad/hr)	Downwind distance (statute miles)	Maximum width (statute miles)	Ground zero width (statute miles)
3,000	0.95 $W^{0.4}$	0.0076 $W^{0.4}$	0.026 $W^{0.4}$
1,000	1.8 $W^{0.4}$	0.036 $W^{0.4}$	0.060 $W^{0.4}$
300	4.5 $W^{0.4}$	0.13 $W^{0.4}$	0.20 $W^{0.4}$
100	8.9 $W^{0.4}$	0.38 $W^{0.4}$	0.39 $W^{0.4}$
30	16 $W^{0.4}$	0.76 $W^{0.4}$	0.53 $W^{0.4}$
10	24 $W^{0.4}$	1.4 $W^{0.4}$	0.68 $W^{0.4}$
3	30 $W^{0.4}$	2.2 $W^{0.4}$	0.89 $W^{0.4}$
1	40 $W^{0.4}$	3.1 $W^{0.4}$	1.5 $W^{0.4}$

Summary

- **On These Two Concepts Groups**
  - Design data are well developed, available
  - Weapon outputs, effects documented, modeled
    - Temperature history
    - Radiation outputs and spectra
    - Shock production
  - Major effort required is in area of
    - Estimating collateral damage/agent release
    - What is required for denial
    - What are consequences of agent release

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Agent Defeat Weapon
Nuclear Baseline Assessment (U)

John St. Ledger
Steve Schafer
Chris Cunningham

November 19, 1996

M Bulmer 10/23/00

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Derived From: See References
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CONCEPT EXPLORATION AGENT DEFEAT WEAPON

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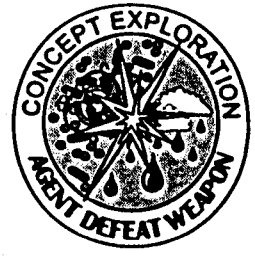
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Baseline Analysis Roadmap

- Targets with additions
- Baseline weapons
- Codes
  - PDCALC6
  - CORES
  - SAMPLL & DUG 1C
  - KDFOC & NEMESIS
  - Agent release
  - SCIPUFF
  - QUICKSTRIKE & CTEM
- Target damage and collateral damage



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FY 97 PROPOSED ACTIVITIES FOR AGENT DEFEAT WARHEAD STUDY (a)

DOE (b)(3)

[redacted] At this point we don't know which or how many of them will be selected for further development.

For the concepts selected, calculations of the performance and collateral effects of the nuclear candidates against the Agent Defeat Weapon target set will be required. A few of the nuclear concepts will also require additional weaponization effort. This would consist of preliminary concept layouts and packaging studies.

[redacted] What would be required for those proposals is presented in more detail on the next page.

DOE (b)(3)

Mel Buchwald 10/23/00
MB

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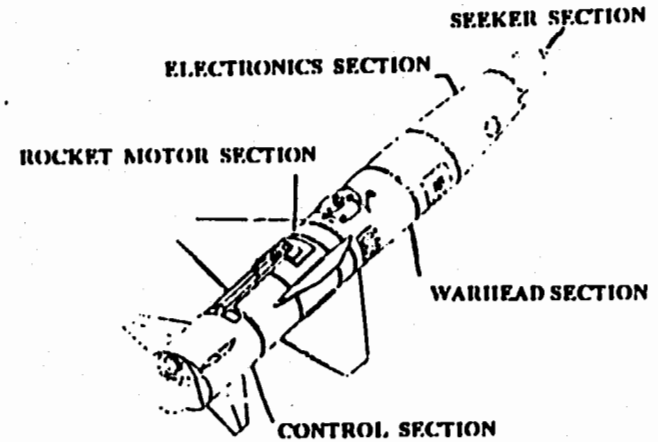
(6) [redacted]

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PLYWD TYPE

Concept Description

- Low-yield nuclear weapon
- Precision guidance
- Standoff capability
- AB/SB/EPW capability



AGM-142-Like Concept

Technical Issues

- pit production/use
- nuclear material production
- warhead certification
- nuclear tests

Benefits

- Neutralization of Bio/Chem agents
- facility and weapon destruction
- Long-term denial
- can defeat area targets
- mitigates target/critical element location uncertainty
- potential collateral damage reduction
- high confidence BDA
- compatible with current and proposed AF weapon systems
- can engage weapons in all stages from manufacture to deployment on delivery platforms

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DEPARTMENT OF THE AIR FORCE
AIR FORCE MATERIEL COMMAND (AFMC)
NUCLEAR WEAPONS INTEGRATION DIVISION

28 June 1996

MEMORANDUM FOR SEE DISTRIBUTION

FROM: SA-ALC/NWIE
1651 First Street SE, B-20360
Kirtland AFB NM 87117-5617

SUBJECT: Agent Defeat Weapon (ADW) Concepts Working Group (CWG) Action Items CWG-6 and CWG-7

1. CWG #6 was held at Eglin AFB, FL on 7 May 96. At this meeting Action Items CWG-6 and CWG-7 were generated. CWG-6 tasks the Mission Analysis Working Group (MAWG) to review the ADW concepts and provide specific questions. The MAWG reviewed the concepts during 17-20 Jun 96. The specific questions from this review are included in the attachment. Response is requested by 31 Jul 96. Although some of the concept questions are unclassified, many of the responses will be classified. Please classify response accordingly with the ADW Concept Exploration Security Classification Guide.

2. Action Item CWG-7 tasks the CWG and MAWG Chairs to schedule a joint meeting to discuss the results from the effort identified in paragraph 1. Concept providers will be required to brief their responses to the questions during this meeting. The joint meeting is scheduled for 6-7 Aug 96 with an ADW Program Review scheduled on 8 Aug 96. Details for these meetings are forthcoming.

3. If you have additional questions please contact Don Erdmann, (505) 846-4001 x206, DSN: 246-4001 x206, FAX: (505) 846-4618.

DONALD R. ERDMANN
ADW CWG Chairperson

Attachment:
Specific Concept Questions (S)

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
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ADW CONCEPT QUESTIONS
CONCEPT 27
Existing Nuclear Stockpile Options.

1. (U) QUESTIONS REGARDING PHYSICAL CHARACTERISTICS:

   a. (U) What are the external dimensions?

   b. (U) What is the case thickness?

   c. (U) What are quantity & characteristics of ADW materials?

   d. (U) What is the toxicity of the by-products?

   e. (U) What are the mass moments of inertia?

   f. (U) How much HE, if any, and what type?

   g. (U) What type of propellant is used?

   h. (U) What is the overall weight?

2. (U) QUESTIONS REGARDING FUNCTIONAL CHARACTERISTICS:

   a. (U) What volume or area is effected by the weapon?

   b. (U) How will dust, debris and other contaminants effect the system?

   c. (U) What weapon outputs should be associated with each weapon and yield combination?

   d. (U) What are the CEP's for each weapon?

   e. (U) What are the available fuse settings for each weapon?

3. (U) QUESTIONS REGARDING LOGISTICAL CHARACTERISTICS:

   a. (U) What restrictions will different weather conditions pose upon the concept?

   b. (U) What intelligence dependencies does the concept need (agent type, target structure, BDA)?

   c. (U) Does the concept need any special handling?

ADW CONCEPT QUESTIONS
CONCEPT 27
Existing Nuclear Stockpile Options.

d. (U) What is the shelf life of the system?

e. (U) What is the time needed to prepare the concept for a launch?

f. (U) What are the VN and GVN numbers for the targets?

4. (U) QUESTIONS REGARDING COST:

a. (U) What is the life cycle cost?

b. (U) What is the average unit cost?

c. (U) What is the disposal cost?

5. (U) QUESTIONS REGARDING PROGRAM MANAGEMENT:

6. (U) GENERAL COMMENTS:

a. (U) What type of testing has been completed?

b. (U) What is the availability of defeat mechanism raw material?

c. (U) Is there any reference material available?

d. (U) What is the impact of missing the target on weapon function?

e. (U) What are the characteristics of the expected radiation field?

f. (U) What delivery accuracy will be required?

g. (U) For any system or subsystem performance specifics, justify or substantiate how these claims were arrived at. Was it due to a system level test, subsystem level test, or was it simulated or analysis performed (i.e. DARPA, contracted, in-house).

ADW CONCEPT QUESTIONS
CONCEPT 27
Existing Nuclear Stockpile Options.

i. (U) Please relate a concepts effectiveness to the ADW consolidated target list? For the ADW consolidated target list, how many sorts of a given concept are needed to defeat or deny access to that target?

j. (U) Can you provide energy spectra that should be used for transport calculations in bunkers with shielding? Or will you do the calculations or the threat scenarios? (radiation concepts only)

k. (U) Quantify collateral effects. Estimate effects - are containers vaporized, ruptured, thrown about, etc? Give some specific examples.

l. (U) We need more data to substantiate the kill mechanisms from these concepts. The radiation contours can be assessed in a straight forward manner - but thermal kill is a very difficult area. Provide the details that lead you to state the fireball will kill all agents. Since heat kill is a time and temperature criteria, how much dispersed agent is pushed out by the shock wave before the fireball temperature kills it. The lethality estimates call for about 2000 degrees for several milliseconds. Can you detail how the material is entrained and show that a conservative analysis kills most agent.

m. (U) Vaporization is certainly a kill criteria. But if you loft globs of spore the heat will kill spore on the outside but given the low thermal diffusivity of spore, the agent in the center may still be viable.

n. (U) Provide some sure-thermal-kill radius based on hydrocode calculations of the shock wave from weapon detonation and fireball temperature.

o. (U) Need to address agent in containers that may be ruptured outside of this sure-kill zone. Please estimate the probability of container rupture.

p. (U) Please provide detailed fallout data on this concept to use as a measure of collateral damage.

ADW CONCEPT ANSWERS
CONCEPT 27 (U)
Existing Nuclear Stockpile Options

J. F. Cuderman, Steve Schafer, Al Baker—Sandia National Laboratories

1. (U) PHYSICAL CHARACTERISTICS

   a. (U) External Dimensions:
   B61-7: 142"long, 13.3" OD; B83: 145"long, 18"OD;
   W80 CM Warhead: 31.5 "long, 12.75" OD.

   b. (U) Case Thickness:
   Not Applicable to non-penetrator systems

   c. (U) Quantity and characteristics of ADW materials:
   Nuclear Package

   d. (U) What is toxicity of the by-products:
   Radiation

   e. (U) What are moments of inertia:
   B61-7: Pitch and Yaw: 819 lb-in^2; Spin: 15,000 lb-in^2
   B83: See Fig. 1

   f. (U) How much HE, if any, and what type:
   Not applicable to nuclear systems since it is not significant part of the ADW material

   g. (U What type of propellant is used:
   Not applicable to these nuclear systems

   h. (U) Overall weight:
   B61-7: 765 lb
   B83: 2467
   W80 CM Payload: 300 lb

DERIVATIVE CLASSIFIER:
J. B. COX 2161, Adv. Sys. Dev. Dept.
Date: 8/1/96
Sources: SAND 79-2422, 7-81
SAND 77-0773, 2/78
CG-W-5 Class. Bul. Guide, 11/8

2. (U) FUNCTIONAL CHARACTERISTICS

   a (U) Volume or area affected by weapon:
   Depends on yield, height of burst

   b. (U) Effect of dust, debris, and other contaminants:
   Little or none

   c. (U) Weapon outputs associated with each weapon and yield combination:

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Radiation, heat, blast , shock—will be provided in effects calculations

[redacted]

DoD 6(3)

a. (U) Restrictions imposed by different weather conditions:
Only those which affect delivery system.

b. (U) Required intelligence:
Target structure, BDA

c. (U) Special handling requirements
Approval by National Command Authority, Nuclear weapon handling procedures.

d. (U) Shelf life of the system :
Indefinite—intent is to maintain stockpile as long as necessary

e. (U) Time required to prepare for launch:
Depends on approval time, state of readiness of weapons and delivery systems.

f. (S) VN and GVN numbers for targets:
See **Attachment 1**

4. (U) Questions Regarding Cost:
These systems are already in stockpile. Therefore there are no development costs involved. In any event, costing is a DOE, not a laboratory, function.

5. (U) Questions Regarding Program Management
There are no questions regarding program management since the weapons are already in stockpile. Any program management issues are handled by the appropriate POG.

6. (U) GENERAL COMMENTS
a. (U) Weapons Testing Completed:
All tests required for certification of the weapons "pre-Test Ban".
b. (U) Availability of defeat mechanism raw material:
In stockpile

m. (U) Vaporization is a criteria, but spores heat resistant.....
See answer to 6-k., above.

n. (U) Provide some sure-thermal-kill radius based on the shock wave from weapon detonation and fireball temperature.
See 6-h.

o. (U) Estimated probability of container rupture outside of "sure kill zone":
Unity

p. (U) Detailed fallout data as a measure of collateral damage:
See Attachment 3 and Cris Cunningham's presentation.

ATTACHMENT3: Fallout Data

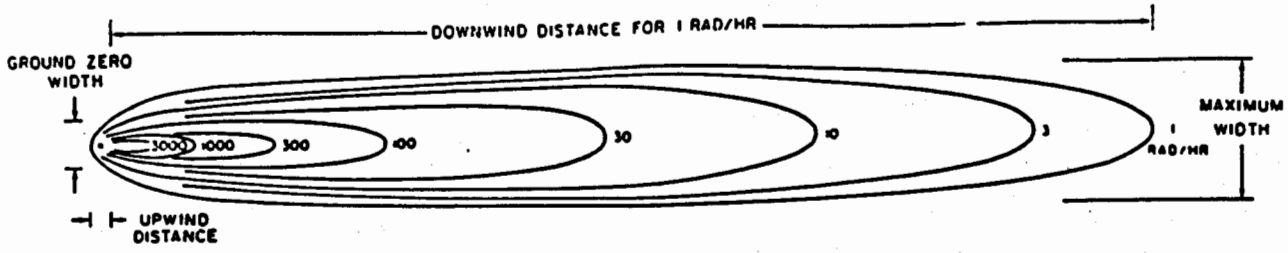


Illustration of idealized unit-time dose-rate pattern for early fallout from a surface burst (The contour dimensions are indicated for a dose rate of 1 rad/hr.)

SCALING RELATIONSHIPS FOR UNIT-TIME REFERENCE DOSE-RATE CONTOURS FOR A CONTACT SURFACE BURST WITH A YIELD OF W KILOTONS AND A 15 MPH WIND

Reference dose rate (rad/hr)	Downwind distance (statute miles)	Maximum width (statute miles)	Ground zero width (statute miles)
3,000	0.95 W^0.45	0.0076 W^0.86	0.026 W^0.45
1,000	1.8 W^0.45	0.036 W^0.86	0.060 W^0.45
300	4.5 W^0.45	0.13 W^0.86	0.20 W^0.45
100	8.9 W^0.45	0.38 W^0.86	0.39 W^0.45
30	16 W^0.45	0.76 W^0.86	0.53 W^0.45
10	24 W^0.45	1.4 W^0.86	0.68 W^0.45
3	30 W^0.45	2.2 W^0.86	0.89 W^0.45
1	40 W^0.45	3.3 W^0.86	1.5 W^0.45

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(U) INTRODUCTION

(U) Desert Storm experience alerted U.S. theater commanders to the fact that major deficiencies exist in our ability to detect and locate critical mobile targets on the tactical battlefield. Possible ways to reduce these deficiencies include the use of sensors of various types to detect and identify SCUDs (or other missiles) with enough timeliness and precision to cue effective counter-attacks before the missiles are launched. Issues pertaining to sensor capabilities and deployment in this situation were analyzed in Reference 1. Another possible defense is to use sensors to detect missile launch and communicate launch time and location information to missile defense systems that can intercept and destroy the missile in-flight. The effectiveness of this defense will depend on sensor and interceptor performance and deployment parameters. The path from concept to a fielded, effective system is arduous, but a simulation analysis, such as is reported here, can provide ballpark figures that will be useful to system designers and operational planners.

(U) This report, as indicated, describes the results of a simulation analysis to evaluate a sensor-to-shooter architecture designed to detect and destroy tactical ballistic missiles (TBMs) during their boost phase. To perform the analysis, the previously-developed SENsor Evaluation Model (SENSEM) code[2], which was written to simulate the detection and identification of critical mobile targets, such as SCUD launchers in transit, was extended to simulate launch detection and boost-phase intercept.

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nterceptor ability was estimated as a function of the time delay from missile-launch to interceptor cue.

(U) SCENARIO DEVELOPMENT

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DOD b(1)

(U) SENSOR DEPLOYMENT STRATEGY

(U) Seismic sensors that have been used in the past to detect and locate Lance missile launches at White Sands Missile Range (WSMR) typically use accelerometers and geophones to measure the low frequency signature of the acoustically-coupled seismic energy associated with the first burn of the rocket motor. Although propagation times are a function of terrain type, detection ranges of 8-10 kilometers have been demonstrated[4]

DOD b(1)

in some of the tests conducted at WSMR. Based upon discussions with sensor hardware experts, a detection probability of 0.9 was assumed for launches within the maximum detection range of the sensor. Launches outside this range were given a detection probability of 0. A value of 10 km was used as the base case maximum detection range but was varied in subsequent cases in order to evaluate the sensitivity of sensor array performance to detection range.

though, that while coverage may be enhanced by closely spaced sensors, such spacing could degrade launch location estimation. This is an area for future study.

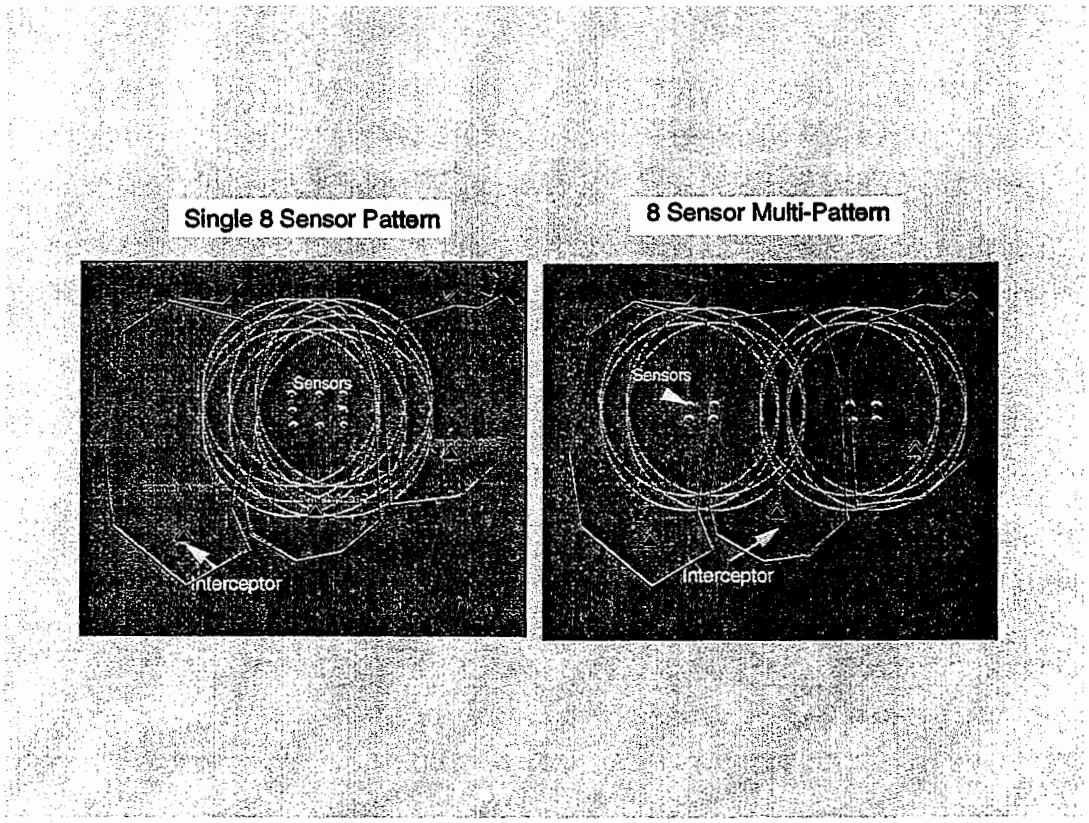


Figure 3. Deployment Patterns for 8 Sensor Array (U)

(U) SENSOR REQUIREMENTS FOR LAUNCH DETECTION AND LOCATION

(U) Sensor arrays were deployed across the three launch areas using the patterns discussed above and SCUD launcher tracks were generated using the SENSEM simulation. Multiple replications (50) were performed for a total of 200 launches and the percent of launches detected by 1,2,3,4,...., or 8 sensors was calculated. The base case results are shown in Figure 4 for a sensor maximum detection range of 10 km. No location solution is possible with less than 3 sensor detections, therefore the bar values for 0 (no detections) and 1 or 2 sensor reports represent detections only. The bars for 3,4,...., or 8 sensor reports represent the percent of launches for which detection and location estimates were made for the indicated array size. For example, for the 16 sensor array case, 19% percent of the launches were detected by only 2 sensors (no location solution) while 28% of the launches were detected by exactly 3 sensors and located after post-processing of the individual sensor data. The solid lines accompanying the bar charts sum the total percent of launches for which 3 or more and 4 or more sensors both detect and estimate launch location. As expected, the percent of launches for which position estimates are made increase as the number of sensors in the sensor array grows, e.g.

(U) Increasing the number of sensors in the array has the beneficial effect of improving the accuracy of the launch location estimate. In Figure 5, for all the cases where a location estimate was made, the conditional cumulative distribution of position errors is shown for the different size arrays. The results show, e.g., that the median estimation error is 400 m for 4 sensors, 100 m for 8 sensors, and about 30 m for 16 sensors and 24 sensors. It should be noted that large position errors can occur, e.g., in excess of 3000 meters. These situations almost always occurred when only three sensors detected the launch and the launch point estimation algorithm failed to find a local minimum (see Appendix).

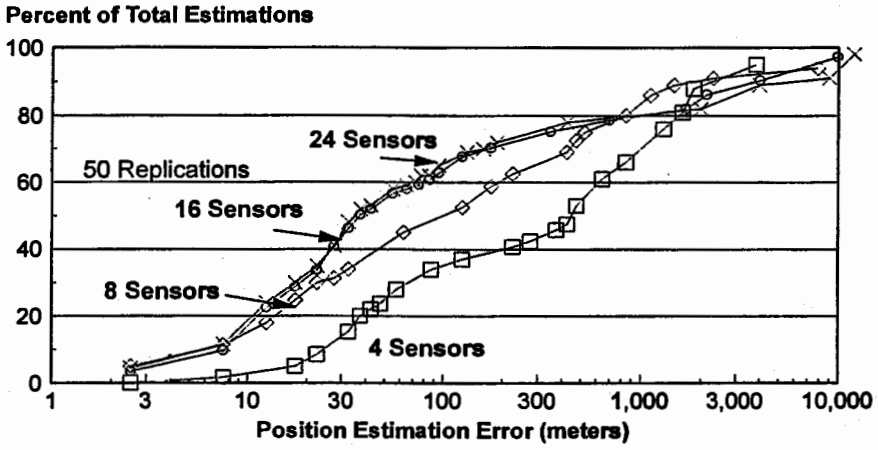


Figure 5. Distribution of Position Estimation Errors (U)

(U) SENSITIVITY OF SENSOR REQUIREMENTS TO DETECTION RANGE

(U) Additional calculations were made to assess the degradation in sensor array performance associated with smaller detection ranges. Although detection ranges of 8-10 km have been observed during test series, the base cases were rerun with a maximum detection range of only 5 km. The sensor deployment locations chosen for the base case (10 km detection range) were clearly not optimum for the 5 km case; therefore the off-line analysis was rerun for the latter case in order to determine more favorable sensor locations for use in the SENSEM model. The results of those calculations indicated that a deployment pattern similar to the base case was optimal for maximizing area covered by 3 or more sensors but modified by closer spacing between sensors.

(U) A comparison of sensor array effectiveness is shown in Figure 6 for both detection ranges. Sensor detection range is obviously a big driver in the performance of boost-phase sensor arrays. For example, with a detection range of 10 km, the 16 sensor array was able to detect and locate over 75% of the launches. However, when the sensor detection range was reduced to 5 km, only 20% of the launches were detected and located. Note that the area covered by a sensor is reduced by a factor of 4 when the detection range is halved, so, at least in the parameter region in which these calculations were done, there is a corresponding approximate factor of four decrease in the detect/locate probabilities.

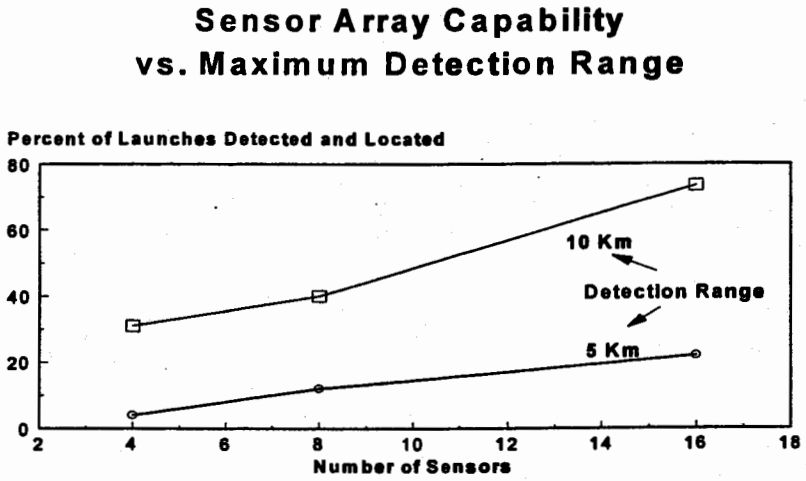


Figure 6. Maximum Detection Range Sensitivity (U)

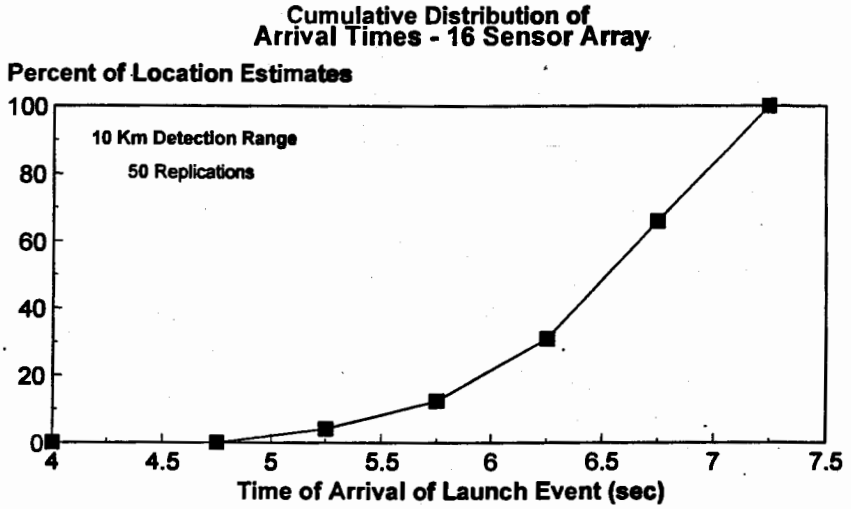


Figure 8. Maximum Arrival Times - 16 Sensor Array (U)

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(U) Detailed Command, Control and Communication (C3) architecture requirements for data transmission between sensors and interceptor platform were not considered in this study. Rather, it was assumed that a seismic sensor array could receive the launch signal

(U) CONCLUSIONS

(U) The results of this study indicate that a moderately small number of capable, reliable, well-placed seismic sensors could successfully detect and locate enemy TBM launches.

(U) The key assumptions underlying this conclusion area:

a. sensors can be suitably emplaced in the launch region and will be operational at the time of launch.
b. sensors will be able to identify TBM launches over the detection range and with the reliability modeled in the simulations.
c. the geology of the launch area is well-represented by the model used in estimating launch location.
d. there are no ambiguous signatures when near-simultaneous launches occur.

(U) In the baseline case, sensors with 10 km detection range and .9 reliability each covered about 25% of the launch area and a 16 sensor array was able to detect and locate ~75% of all launches. If the detection range is only 5 km, then only about 25% of the launches in the scenario studied can be detected and located. In general, launch detection

by four or more sensors is required to provide accurate location estimates, so the density and overlapping patterns of the sensors are important determinants of array performance. In this study, for 16 sensors the density is 16/(25*50)=1 sensor per 78 km^2, and this figure might be used to provide a rough estimate of sensor requirements in other launch scenarios. Neither the launches nor the sensors were uniformly distributed throughout the launch area in this study, so 'results may vary' in other applications.

(U) In summary, two components of this proposed boost-phase sensor-to-shooter architecture were analyzed. The detection and location phase seems promising although some risks are inherent, such as geology uncertainty, and a variety of issues pertaining to sensor emplacement, performance, and data processing would need to be resolved. On

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(U) In summary, two components of this proposed boost-phase sensor-to-shooter architecture were analyzed. The detection and location phase seems promising although some risks are inherent, such as geology uncertainty, and a variety of issues pertaining to sensor emplacement, performance, and data processing would need to be resolved. On

REFERENCES

1. Sensor Data Fusion for Location of Critical Mobile Targets (U), D.A. Snyder, J.I. Crowther, SAND94-0726, Secret, April 1994.

2. Sensor Evaluation Model (SENSEM) User Manual (U), Sandia National Laboratories, Nov 1996, Unclassified.

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4. Seismic and Acoustic Measurement of a Lance Missile Launch - WSMR, Aug 10-11,1992 (U), R.S.Harding, Sandia National Laboratories, November 25, 1992, Unclassified.

5. Ballistic Missile Threat Specification (U), BMDO, June 1994, Secret.

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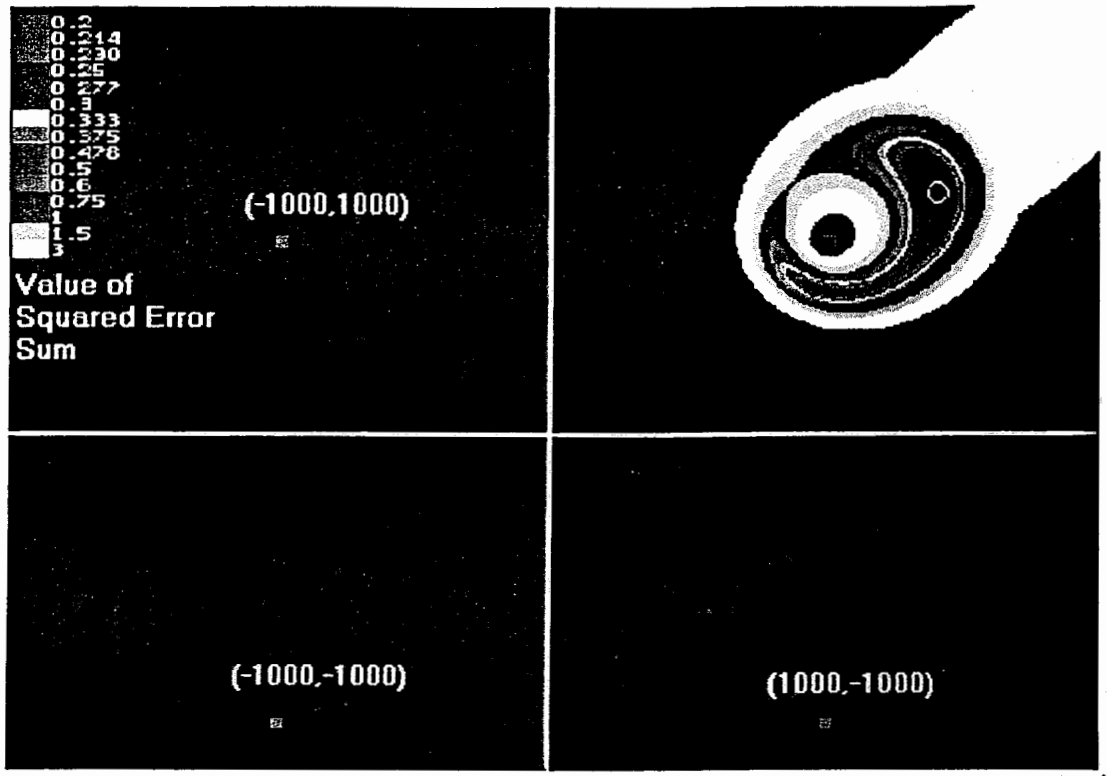


Figure A3. Multiple Minima on Cost Function

Launch Point Estimation for a Three Layer Model

Truth Model TOA:

The "actual" time of arrival (TOA) of the seismic signal at a sensor located a distance r from the source location is

$$\text{TOA} = t_{oa} = \frac{2d_1}{c_1 \cos\theta_1} + \frac{2d_2}{c_2 \cos\theta_2} + \frac{1}{c_3}\left[r - 2(d_1 \tan\theta_1 + d_2 \tan\theta_2)\right] \qquad (1)$$

where d is the thickness, c is the sound speed, and θ is the refraction angle at the respective layers.

Let θ_{1m} and θ_{2m} be the refraction angles in layers 1 and 2 which minimize t_{oa}. Then

$$\sin\theta_{1m} = \frac{c_1}{c_3}$$
$$\sin\theta_{2m} = \frac{c_2}{c_3} \qquad (2)$$

If c_1 or c_2 is greater than c_3, the minimum time path will never be through layer 3. Also,

acoustic time of arrival = r/c_0 (3)

surface wave time of arrival = r/c_1 (4)

1st refracted wave TOA = $$\frac{2d_1}{c_1 \cos\theta_{1m}} + \frac{1}{c_2}\left[r - 2d_1 \tan\theta_{1m}\right] \quad (5)$$

2nd refracted wave TOA =

$$t_{oa} = \frac{2d_1}{c_1 \cos\theta_{1m}} + \frac{2d_2}{c_2 \cos\theta_{2m}} + \frac{1}{c_3}\left[r - 2(d_1 \tan\theta_{1m} + d_2 \tan\theta_{2m})\right] \quad (6)$$

If more than three layers are included in the model,

nth refracted wave TOA =

$$t_{oa} = \sum_{i=1}^{n-1} \frac{2d_i}{c_i \cos\theta_{im}} + \frac{1}{c_n}\left[r - 2\sum_{j=1}^{n-1} d_j \tan\theta_{jm}\right] \quad (7)$$

The actual TOA will be the minimum of the above TOAs.

Measured TOA:

The "measured" TOA, t_{oam}, is obtained for each of the sensors by taking the corresponding t_{oa} and adding a random measurement error (standard deviation input by user) that represents the accuracy of the sensor. The smallest of the measured TOAs is taken to be a reference and a relative measured TOA, rt_{oam}, is obtained. Corresponding to these relative measured TOAs there are relative actual TOAs, rt_{oa}. The sum of the squared differences between these two values will be used to determine a launch point estimate.

Launch Point Estimate (LPE):

Let $rt_{oa}(x,y)$ be the actual relative TOA obtained when the source is located at (x,y). Then a two dimensional search is performed over a region determined by the maximum range of the sensors looking for the local minima of the function

$$L(x,y) = \sum_{k=1}^{n_s}\left[rt_{oak}(x,y) - rt_{oamk}\right]^2 \quad (8)$$

where n_S is the number of sensors within range of the source. An error is issued if n_S is less than three.

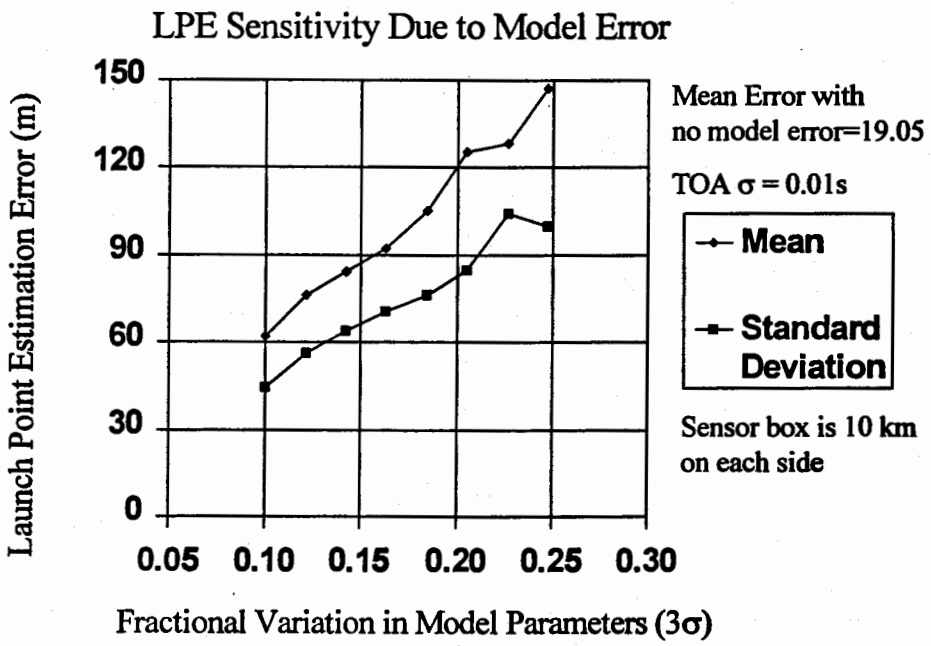


Figure A4. LPE Sensitivity - 10 km Case

A second case, with the sensors in a 2 km box, is provided in Figure A5 to illustrate the reduced sensitivity of the LPE when the sensors are more closely spaced.

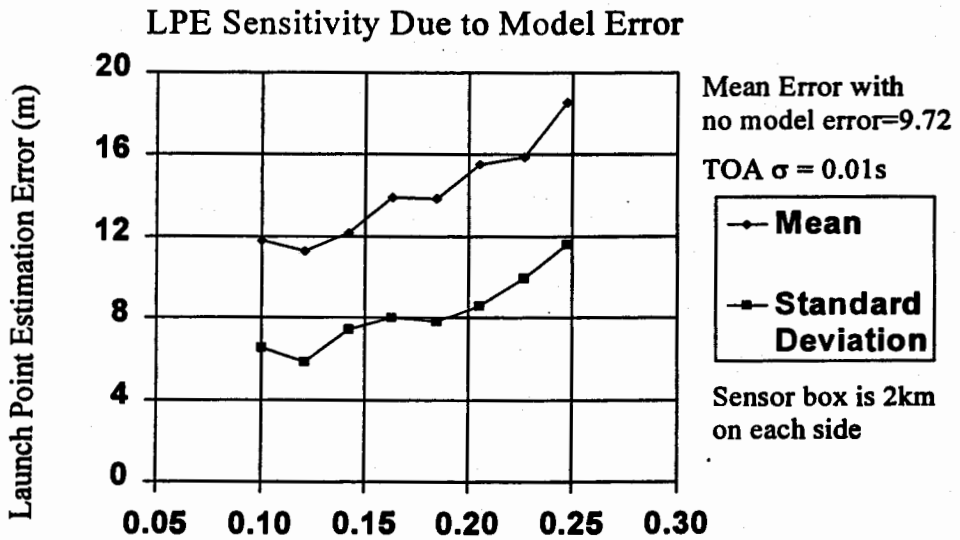


Figure A5. LPE Sensitivity - 2 km Case

April 10, 1996

[redacted]

Sandia POC: Jon Rogers, MS 0419, Dept. 5412, (505)844-3872

[redacted]

1. What initiatives are currently underway?

A. Tactical Unattended Ground Sensors (TUGS)

The TUGS program objective is to develop seismic, acoustic, and magnetic sensors for monitoring and characterizing underground facilities. Specific TUGS tasks are indications and warnings (detection of activity), equipment identification and location within the facility, and battle damage assessment. Hand emplaced sensor units will be developed for the Counterproliferation Advanced Concept Technology Demonstration (ACTD) in FY98. An air delivery capability will be developed in late FY98 and FY99.

Sponsor: Defense Nuclear Agency

POC: Brad Parks, (505)844-6883

B. Sensor Evaluation Model (SENSEM)

Sandia's SENSEM computer simulation model provides a means to investigate several important aspects of underground facilities. [redacted] Users also deploy packages of various types of ground-based sensors to collect intelligence on vehicle movements.

Classified by: R. G. Easterling, Mgr., New Initiatives Dept. 5412, 4/10/96,
Derived from: [illegible]
Declassify on: [illegible]

Using SENSEM, users can represent operational activities of critical systems such as Multiple Rocket Launchers and tactical missiles as they move from underground hide sites to firing positions and return to hide sites. The utility of ground-based sensors can be evaluated in identifying and initiating the engagement of these targets during windows of vulnerability.

SENSEM can also be used to represent military and civilian traffic on the road network to include traffic patterns that might be characteristic of critical underground facilities. From these representations, investigations can be conducted of our ability to identify the location and operational status of important facilities through analysis of traffic patterns.

POC: Jim Crowther, (505)844-1206

C. Remote Induction of Signals into Power and Communication Lines

DOE-supported technology presently being developed addresses close-in survey to detect and characterize underground facilities. The present survey capability is very limited for covert operations. However, a closely associated capability has been demonstrated to be technically viable in the course of detecting and characterizing underground structures. This capability is remote signature coupling for two-way communication into and out of underground structures. The latter capability can support such intelligence needs as: (1) remote location of previously intercepted equipment acquired by a hostile operation and placed in service on the power grid at an unknown location; (2) covert transmission of operative messages or information from clandestinely installed sensors inside a facility; (3) intra-facility/sensor communication; (4) remote interrogation of a suspect power grid to estimate its linear extent to unknown termination points; and (5) (not yet demonstrated) remote imaging of the physical location and distribution of the power grid through induction of highly unique signals onto the suspect grid to facilitate remote tracking of segments of high interest.

POC: Dan Cress, (505)844-7182

D. Coherent Change Detection (CCD)

CCD is a technique that uses 2 complex radar images in a way that permits the detection of extremely subtle changes in the earth, e.g., vehicles traveling on dirt roads. This technique is currently being used to detect evidence of activity around sites such as chemical and biological facilities.

POC: Tom Prevender, (505)844-8768

E. Airborne Multisensor Pod System (AMPS)

AMPS consists of three pods carried on a P-3 Orion aircraft. AMPS Pod 1 contains a Synthetic Aperture Radar (SAR), AMPS Pod 2 contains a Multisensor Imaging system (MSI), and AMPS Pod 3 (in development) contains Effluent Species Identification (EFI) sensors. The data from the AMPS Pods can be used for Coherent Change Detection (CCD), or multisensor data fusion. The SAR Pod is being upgraded to an Interferometic SAR (IFSAR) using two antennas which will result in high-quality terrain elevation maps (3-D). AMPS has been used to observe underground facilities at the Nevada Test Site (NTS) through characterization of surface features such as ground subsidence, adit identification, and muck pile changes.

POC: Bob Huelskamp, (505)844-0496

F. Gravity Gradiometry

Variations in the local gravity field can be used as indicators of voids or structures underground. Measurement of the gravity field and its gradient can locate underground structures. Recent work has been directed toward both the improvement of the gravimeters used to measure the gravity field and the signal processing algorithms used to analyze the data.

POC: Bob Asher, (505)844-5900

2. What enhancements are needed?

[redacted]

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Micro Sensor Capabilities

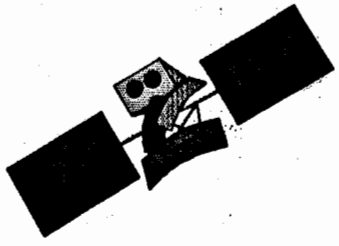
- Imaging
- Seismic
- Acoustic
- Chemical
- Biological
- RF Tags
- Electromagnetic Field
- Radar
- Nuclear
- Accelerometer











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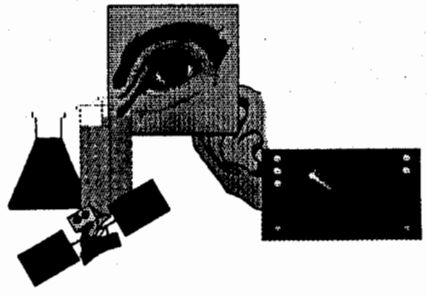
Sensor Fusion Process

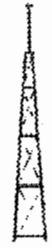
Estimate Target Site Characteristics
Knowledge of Appropriate Sensor Measurands

→

Risk Assessment
Sensor Data Acquisition Plan
(Sample Rate, Patterns, Filters, etc.)

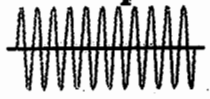
↑ **New Estimates**





↓ **New Paths/ Sensing Locations**

Interpretation of Raw Data Using:





- **Expert Systems**
- **Physical Models**
- **Statistics**
- **Learning Algorithms**

(Neural Nets, Genetics, etc.)

←

Microbot Paths/Sensing Locations
Sensor Data Acquisition Control

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Special Projects Department

Impact of CTBT

The Comprehensive Test Ban Treaty (CTBT) bans any nuclear weapon explosion or other nuclear explosions

- **Constrains the development of new-design weapons**
  - Will result in some loss of confidence in the nuclear weapons stockpile
- **The ability of the US to live with a ban on nuclear testing depends on having a vigorous Stockpile Stewardship Program (SSP).**
  - Guard against aging-related problems
- **The SSP is designed to:**
  - Provide the capability to survey and assess the stockpile for problems
  - Replace weapons components as needed
  - Certify the rebuilt weapons

(CTBT) has reduced our flexibility and options to meet future nuclear deterrent requirements

The CTBT prohibits nuclear explosions. In the past, the nation relied on full-scale integral nuclear testing to ensure the safety, reliability, and performance of our weapons. Furthermore, we relied on nuclear testing to ensure that our systems continued working as they aged.

The CTBT will constrain treaty-compliant nations from making significant advances in nuclear weapons.

Our ability to certify modifications, such as a life extension refurbishment of the enduring stockpile, depends on the success of the Stockpile Stewardship Program (SSP). The success of SSP, in turn, depends on a competent and motivated cadre of nuclear weapons experts, the accelerated strategic computing initiative (ASCI), new experimental facilities, infrastructure improvements, archiving, and funding.

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Drivers

The drivers for change in a test-constrained nuclear stockpile

National Strategy & Policy

- Response to the geopolitical environment
- START (and other) arms control treaties
- Nuclear policy
- National budget constraints
- Regulatory laws and treaties

DoD Initiatives

- Force posture changes
- New or replacement delivery platform acquisition programs
- Changes in Military Characteristics
- STS environments
- Mission Needs Statements

Technology

- Sunset technologies
- Evolution of nonnuclear technologies
- Improvements in advanced conventional weapons
- Advances in defenses

DOE Initiatives

- Stockpile Life Extension
- Safety and Use Control Policy
- Performance margin maintenance and improvements
- Manufacturing streamlining
- Specific stockpile issues

Nuclear Weapons Program

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The four major drivers for change are as follows:

1. National strategy and policy. The United States will adjust its security strategy and policy as the world changes. Treaties, such as START, will likely force changes in the deterrent structure. National nuclear policy will continue to evolve. There will likely be budget constraints on both DOE and DoD. In addition, laws and treaties, particularly in the environmental area, make components extremely expensive or impossible to replace as they were originally designed.

2. DoD initiatives. As many of the DoD delivery platforms reach the end of their lifetime, they will need to be replaced. This presents an opportunity to reevaluate the required military characteristics in light of the post – cold war era. The evolution of technology will probably lead to changes in the defined stockpile-to-target sequence (STS), thus placing new requirements on warhead designs. In addition, new mission needs statements could force changes in both the military characteristics (MCs) and STSs.

3. DOE initiatives. As existing warheads reach the end of design life, we will rebuild the warheads through the stockpile life extension programs (SLEPs). DOE must ensure the systems meet the MCs and STSs, but some of the components will be different. We have seen an evolution in surety standards in the past, and as the terrorist threat evolves, we should expect to see some further evolution in these requirements. DOE is responsible for the safety, surety, and performance of US nuclear weapons. Our confidence rests primarily on our nuclear test history. If we find reason to believe that we do not have enough performance margin in some systems, we may need to make a change. The manufacturing infrastructure is being sized and configured for a post–cold war era, but it will produce some components that are different from those originally manufactured; maintaining confidence will be a challenge. We may also find something in our surveillance program that could force change.

4. Technology. Sunset technologies, such as we have seen in the electronics industry, will force change. There are components and materials that are no longer available on the market; the W76 mount material and [redacted] are examples. The evolution in the nonnuclear technologies can affect delivery system capabilities. Improved advanced conventional weapons may replace nuclear weapons in some areas. Finally, changes in the defense systems may force changes in the US force posture.

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Drivers

Secretary of Defense Richard B. Cheney, November 12, 1991 remarks to the San Diego Union editorial board

" Unfortunately, if you look at the historic record, we have never, ever gone through one of these periods and gotten it right. We've always screwed it up. Every single time when it's happened previously we've been so quick to cash in the peace dividend, to demobilize that force, that within a very short period of time we find that our weakness in and of itself becomes provocative and tempts others to do things they shouldn't attempt; that we always end up having, once again, to commit the force some place – we get in trouble in the world and have to send in troops; that we find ourselves with troops that are not well trained or well equipped, not prepared to go to war."

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This quotation from former Secretary of Defense Cheney articulates the difficulty of preserving force capability and flexibility for the future.

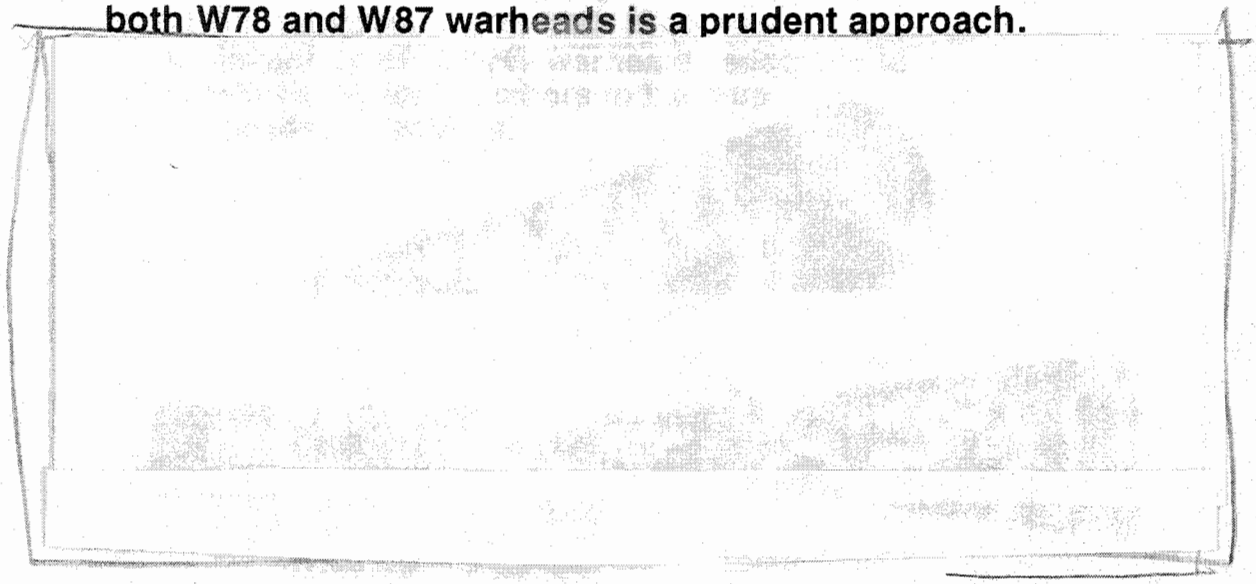
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SECRET RD Classifier: Thomas K. Scheber, Project Leader, NWT Derived from: LA-4000, Rev. 7, 9/94

Change

Guard against failure of ICBM warheads (U)

- **The Air Force plan to employ a MMIII START II force with both W78 and W87 warheads is a prudent approach.**



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Under START II, the Air Force plans to deploy both the W78, currently on the Minuteman III (MMIII), and the W87, currently on the Peacekeeper, on the MMIII intercontinental ballistic missile (ICBM) force.

However, the Air Force plan provides a prudent approach to ensure a backup warhead capability.

The Air Force estimates that it will cost approximately $350 million to adapt the W87 warhead to the MMIII delivery system.

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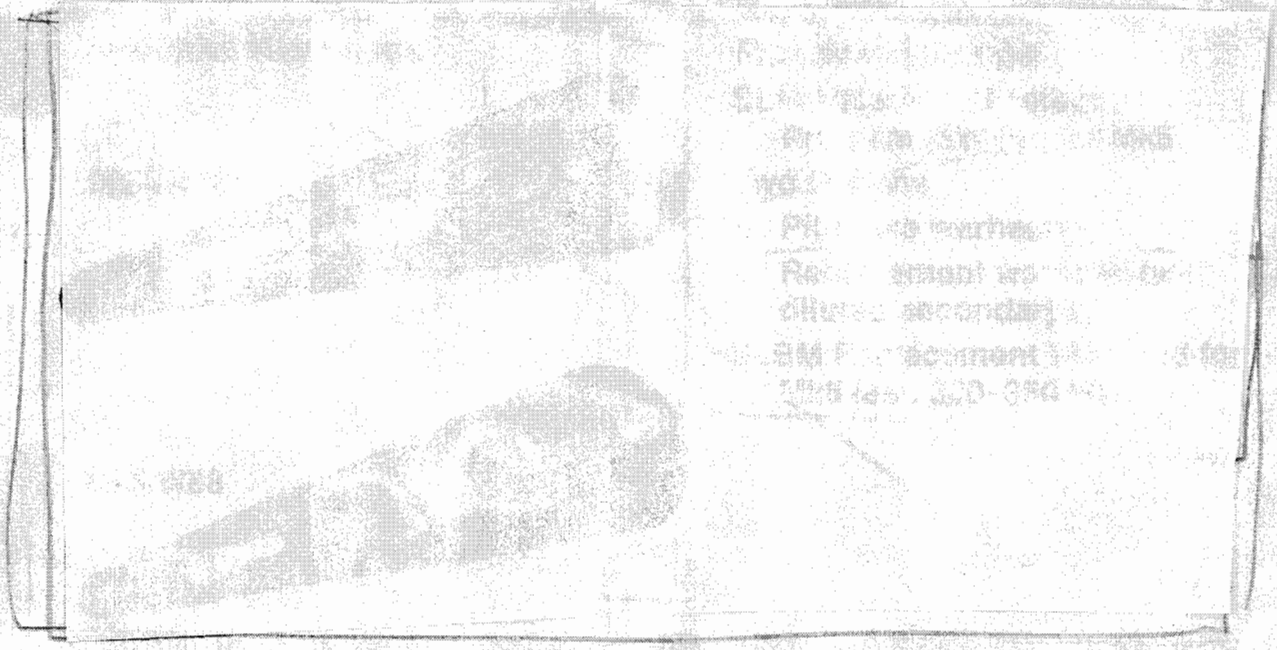
CIC-1/99-0685

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Classifier: Thomas K. Scheber, Project Leader, NWT
Derived from: LA-4000, Rev.7, 9/94

Change

Guard against failure of SLBM warheads (U)



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The W76 and W88 are currently deployed on the submarine-launched ballistic missile (SLBM) force.

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DOE
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The Navy requested that the DOE initiate the SLBM Warhead Protection Program (SWPP) as backup to the W76 and W88 warheads.

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Enhancing Confidence in the Nation's Nuclear

Livermore researchers combine materials research, experiments, and advanced numerical models to anticipate any problems in America's aging nuclear weapons.

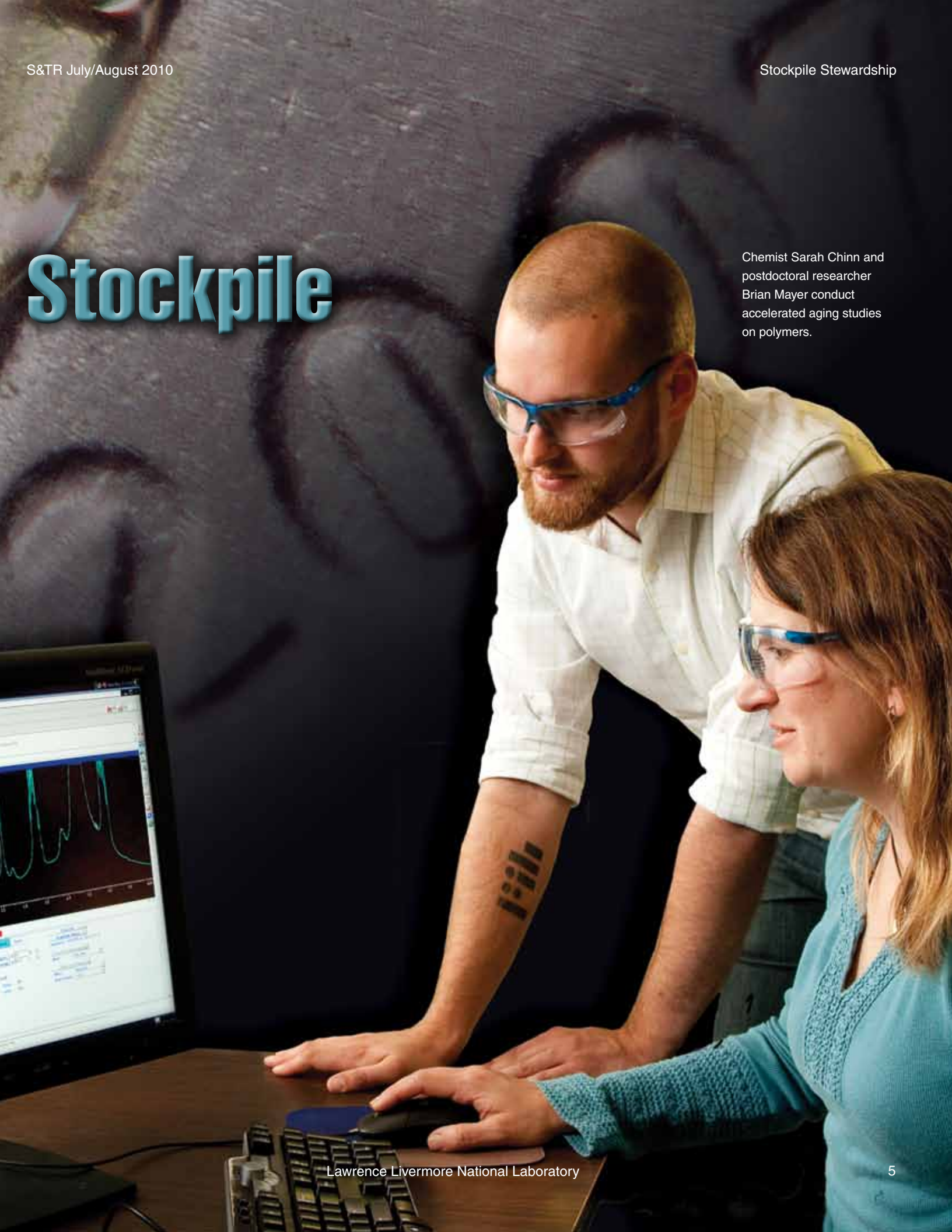
SOME experts compare the National Nuclear Security Administration's (NNSA's) mission to maintain and enhance the safety and security of America's nuclear stockpile with the National Aeronautics and Space Administration's mission to safely land a human on the moon. The comparison is often made because nuclear weapons are extremely complex devices, with thousands of components that must work together seamlessly to produce a nuclear detonation. What's more, since 1992, scientists can no longer check the performance of nuclear weapons by detonating them underground at the Nevada Test Site. (See the box on p. 6.)

Nuclear weapon components are made of various materials such as high explosives (HEs), steel, plutonium, uranium, and polymers (plastics). Scientists have found age-related changes in some of the components and materials in weapons removed from the stockpile and disassembled. These changes are occurring, in part, because many weapons have been in the stockpile longer than originally intended. Plastics can break down and give off potentially destructive gases, metals can corrode and weaken, and coatings can deteriorate. Some materials may change properties unpredictably in response to the high radiation fields, fluctuating temperatures, and other environments to which nuclear weapons are subject.

In the absence of developing new nuclear weapons, experts must work to extend the life of existing units and understand how their constituent materials and components age. Scientists conduct a comprehensive program of weapon surveillance (close examination), laboratory experiments, and maintenance and refurbishment of components. Data from all activities are used to refine computational models, some of which serve as electronic surrogates for underground testing. These combined activities, which require the efforts of



Stockpile



Chemist Sarah Chinn and postdoctoral researcher Brian Mayer conduct accelerated aging studies on polymers.

chemists, materials scientists, engineers, physicists, and computer scientists, are called stockpile stewardship. The Stockpile Stewardship Program has been enormously successful to date and has permitted the directors of Lawrence Livermore, Los Alamos, and Sandia national laboratories to annually assess the status of the stockpile and conclude that currently a need does not exist for nuclear testing.

Livermore chemist Bob Maxwell notes that relying solely on routine surveillance of nuclear weapons provides little insight into possible future changes in materials and components that could affect safety or performance. "Inspecting or testing components doesn't help us predict beyond today," he says. "For example, a test of HE material taken from a stockpiled unit may tell us the material is capable of detonating this month but does not necessarily give us confidence in its performance a decade from now."

To gain added confidence, Livermore experts lead numerous efforts in NNSA's Enhanced Surveillance Campaign, aimed at producing informed estimates about how nuclear weapon materials and components will likely change over the next one to two decades. Results from enhanced surveillance efforts are fundamental to life-extension programs, which entail refurbishing or replacing parts to extend the time that a specific weapon system can safely and reliably remain in the stockpile. "We must look 15 to 20 years in the future because it can take that long to fix a problem, given the current lean nuclear weapons infrastructure," explains Bill McLean, manager of Livermore's Enhanced Surveillance Campaign.

For several years, a key thrust of enhanced surveillance centered on studying the properties and aging of plutonium pits found in every modern nuclear weapon. In 2006, the two NNSA nuclear design laboratories—Lawrence Livermore and Los Alamos—issued a joint report stating that "subtle age-induced changes in the atomic structure and composition of plutonium do not, in themselves, limit the lifetime of U.S. weapon pits," and "the majority of plutonium pits for most nuclear weapons have minimum lifetimes of at least 85 years." That finding has permitted Livermore stockpile stewards to shift the focus of their attention to obtaining a better scientific understanding of how other weapon materials and components age and interact during the decades they remain in the stockpile.

Some Livermore enhanced surveillance experiments artificially age materials and components by subjecting them to high temperatures or intense gamma or neutron radiation. Other efforts focus on developing new diagnostics and nondestructive tests. Data obtained from

Managing the Nation's Ever-Shrinking Nuclear Arsenal

The nation's current nuclear stockpile consists of sea-based, land-based, and air-carried systems. For decades, the performance of the complex nuclear explosive package as well as the nonnuclear components in these weapon systems was confirmed with underground tests conducted at the Nevada Test Site. Since the nuclear test moratorium was adopted in 1992, the U.S. has deployed no new weapons, while thousands of existing weapons have been retired or dismantled.

Under the 2002 Moscow Treaty on Strategic Offensive Reductions, the U.S. has been reducing the number of its operationally deployed nuclear weapons to between 1,700 and 2,200 by 2012. In April 2010, U.S. President Barack Obama and Russian President Dmitry Medvedev signed a new arms reduction pact that pledges to reduce the number of operationally deployed, strategic nuclear weapons in both countries and commits the nations to adopt new procedures for verifying which weapons each country possesses. Under this treaty, called New START, both countries will be limited to 1,550 ready-to-use, long-range nuclear weapons. In the future, as the number of U.S. weapons shrinks, fewer weapons will be available for disassembly, underscoring the importance of nondestructive testing of existing weapons and science-based studies of materials and components.

The New START force reductions are a key step in implementing the Obama administration's strategy to reduce nuclear dangers, which is described in the 2010 Nuclear Posture Review (NPR). NPR emphasizes as one of its five major findings the need for the nation to sustain a safe, secure, and effective nuclear arsenal as long as nuclear weapons exist.

Stockpile stewardship is a responsibility of the National Nuclear Security Administration (NNSA), which was established by Congress in 2000 as a semi-autonomous agency within the Department of Energy. The Stockpile Stewardship Program includes science and engineering experiments and computer simulations to study the mechanisms of how nuclear weapon components age. NNSA assesses each nuclear weapon to detect or anticipate potential problems that may come about as a result of aging. As part of that effort, each weapon receives routine maintenance and surveillance (a thorough examination). In addition, the agency extends nuclear warhead lifetimes through the refurbishment of critical components and safely dismantles and disposes of units that have been retired.

NNSA nuclear weapons laboratories—Los Alamos, Lawrence Livermore, and Sandia—assess the health of the current stockpile, design the components and systems for the life-extension programs, and certify the life-extended models when they enter the stockpile. Over the past decade, NNSA has funded new experimental capabilities at the laboratories, including the National Ignition Facility at Livermore and the Dual-Axis Radiographic Hydrodynamic Test Facility at Los Alamos. One of the most far-reaching efforts was instituting the program now known as Advanced Simulation and Computing, which permits the computational "testing" of components and entire systems, and which has impelled a transformation of the nation's supercomputing industry.

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LLNL DESIGN OPTIONS

A-05-244(R)

9 June 2005

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LLNL RRW Design Options for the Limited POG (U)

Presented to:
RRW POG mtg. #2
9 June 2005



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MINUTES OF THE 2nd RELIABLE REPLACEMENT WARHEAD PROJECT OFFICERS GROUP MEETING (U)

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9 June 2005

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MINUTES OF THE 2nd RELIABLE REPLACEMENT WARHEAD
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C	LIST OF ATTENDEES
D	CONSOLIDATED RRW REQUIREMENTS
E	RRW POG STUDY PLAN BRIEFING TO THE NWCSSC
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L	SYSTEM PERFORMANCE & ASSESSMENT SUBCOMMITTEE (SPASC)
M	VULNERABILITY WORKING GROUP (VWG)
N	LANL PRIMARY DESIGN AND CERTIFICATION REVIEW [Limited Distribution – Addendum 1]
O	LANL RRW DESIGN OPTIONS [Limited Distribution – Addendum 1]
P	LLNL RRW DESIGN OPTIONS [Limited Distribution – Addendum 2]
Q	RRW CLASSIFICATION MANAGEMENT
R	RRW POG LONG-TERM SCHEDULE

Background

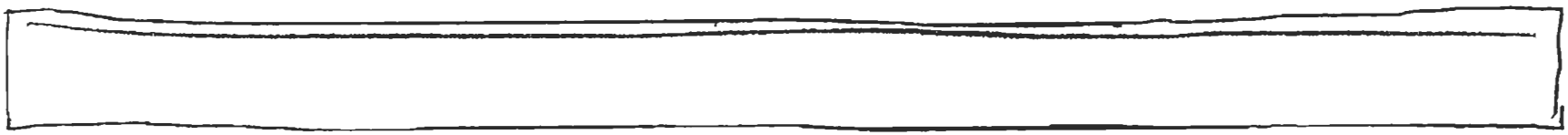
- **NWC approved creation of a Joint Reliable Replacement Warhead Project Officers Group (RRW POG) on 23 March 2005**

- **NWC memorandum dated 11 April 2005 establishes a RRW POG**
  - Oversee a laboratory design competition for an RRW
  - First deployment on SLBM
  - 18 month study
  - Assess technical feasibility, design definition and cost
  - At the conclusion of the study, the RRW POG will present the preferred RRW design options and recommendations to the NWCSSC for approval
  - Requested Lead Project Officer brief NWCSSC on study plan in July 2005 including goals, strategy, and milestones

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Reliable Replacement Warhead Study Goals

- **Sustain long term confidence in a safe, secure and reliable stockpile**
- **Enable transformation to a responsive nuclear weapon infrastructure**



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Strategy

- **Conduct a design competition between LANL and LLNL**
  - Reliable Replacement Warhead
  - W76 Risk Reduction Warhead
- **Conduct an independent peer review of the LANL and LLNL design options**
- **POG evaluate options, make recommendations, and issue report**

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Key Players

MEMBERS

- Navy SSP (Chair)
- Air Force XOS (Co-chair)
- USSTRATCOM
- DATSD (NM)
- NNSA NA-11
- NNSA NA-12
- LANL
- LLNL
- SNL/NM
- SNL/CA
- ITT
- LMSSC
- PMOSSP (SPF)
- Air Force NWCA

OFFICIAL OBSERVERS

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- OPNAV
- Pantex
- KCP
- Y12

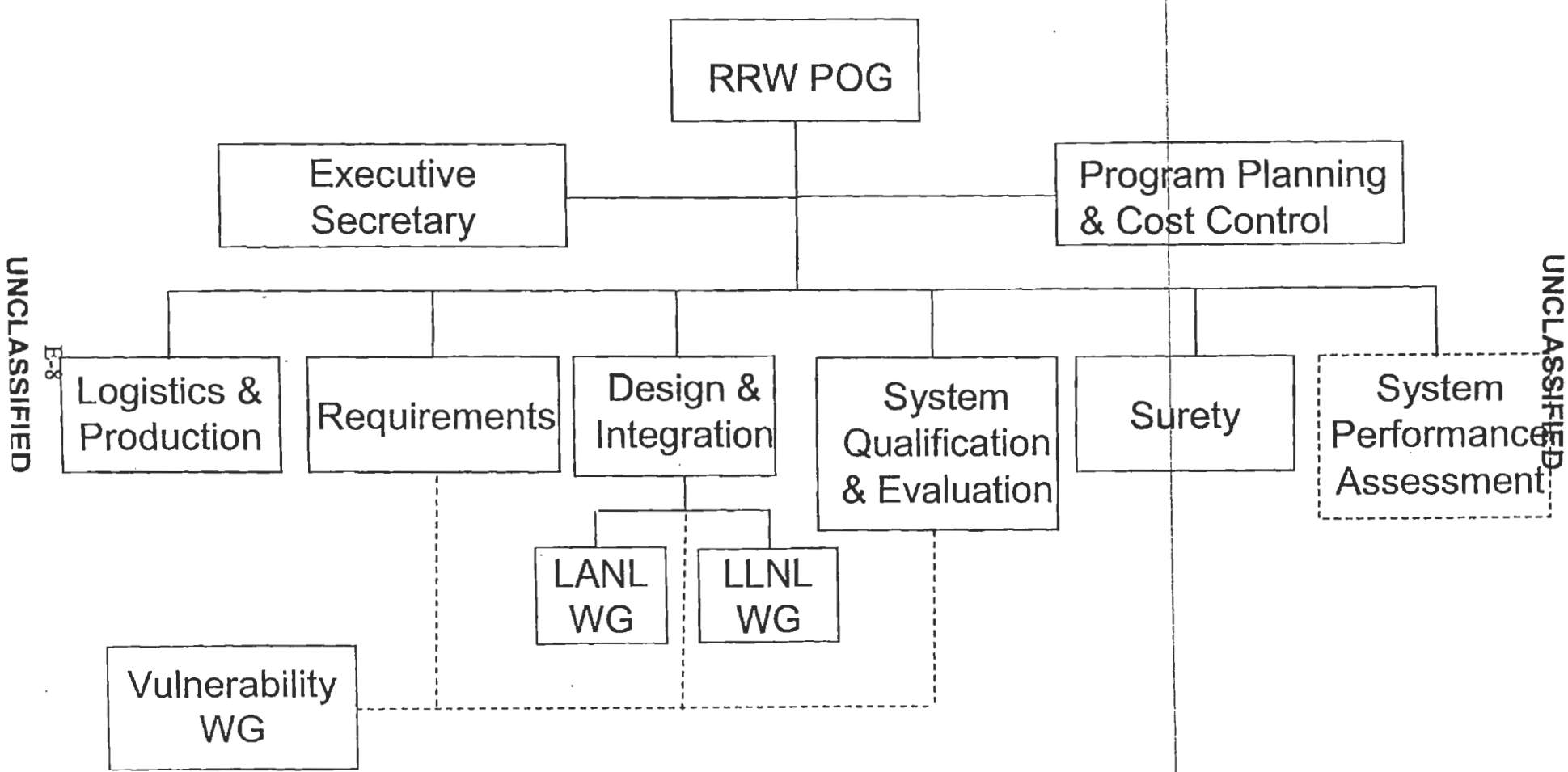
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RRW Organizational Chart



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Study Scope

Reliable Replacement Warhead (RRW)

- **Feasibility/design definition and cost study**
  - Laboratory design competition
  - First deployment on SLBMs
- **Considerations:**
  - FPU ~ 2012
  - [redacted] b(5)
  - Enable transformation to a responsive infrastructure
  - "Lifecycle" review of infrastructure requirements
  - [redacted] b(5)

W76 Risk Reduction Warhead

- **Design Concept study**
  - Minimum cost W76 replacement as a backup for the RRW (risk reduction measure)
  - Laboratory design competition
  - FPU ~ 2010

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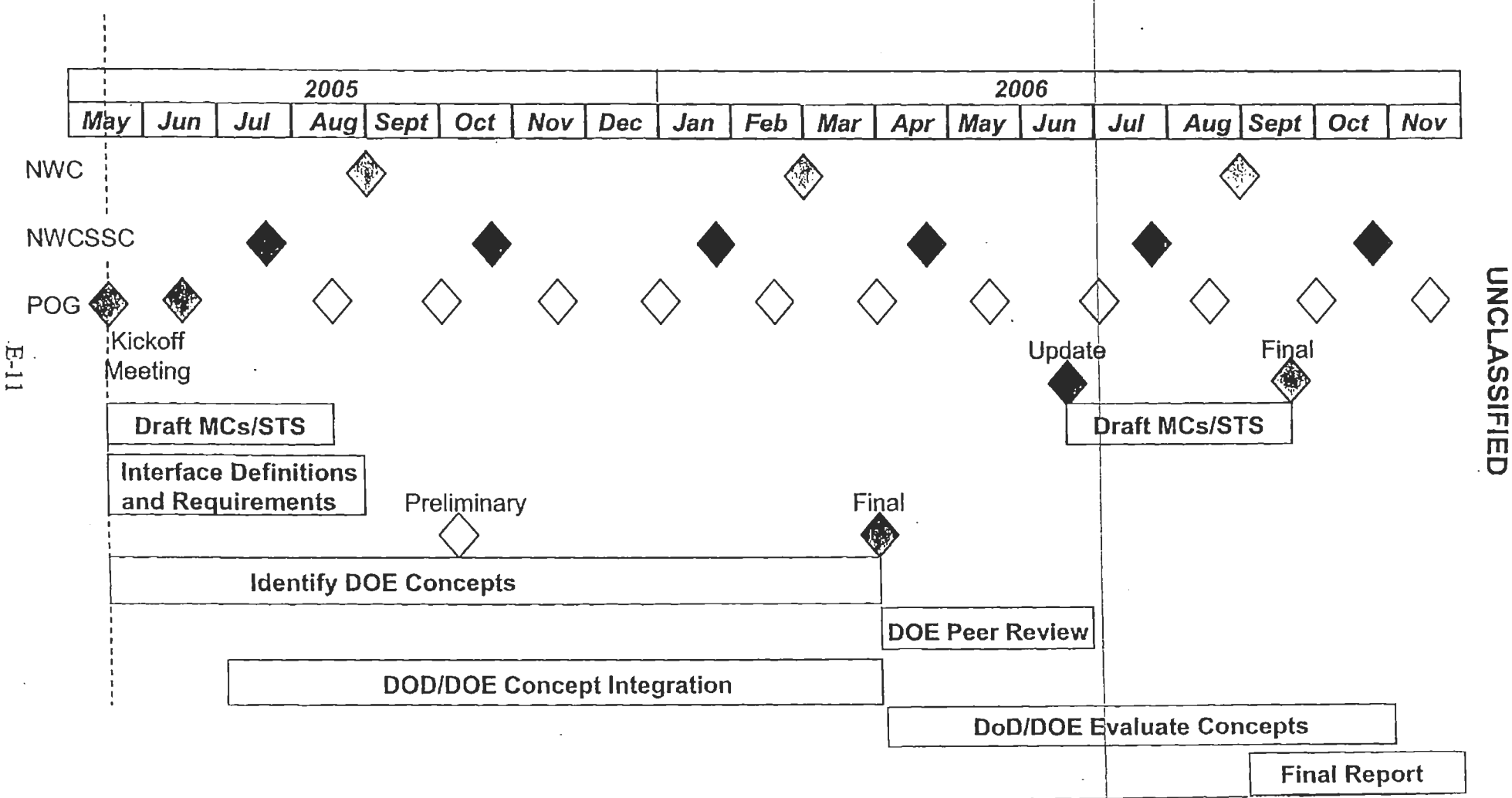
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Priorities

- **Safety**
- **Security/Use Control**
- **Cost**
- **Certifiability**
- **Manufacturability**
- **Reliability**
- **Survivability**
- **Yield**
- **Longevity**

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RRW Study Plan



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Study Status

- **RRW POG has been formed with supporting subcommittees**
  - Kickoff Meeting: 11 May 2005
  - 2nd Meeting: 9 June 2005
- **Subcommittee charters developed and approved by POG**
- **Draft Military Characteristics (MC) and Stockpile-to-Target Sequence (STS) documents being prepared with STRATCOM interaction**
- **DoD and NNSA are working together to prepare an RRW Classification Guide**

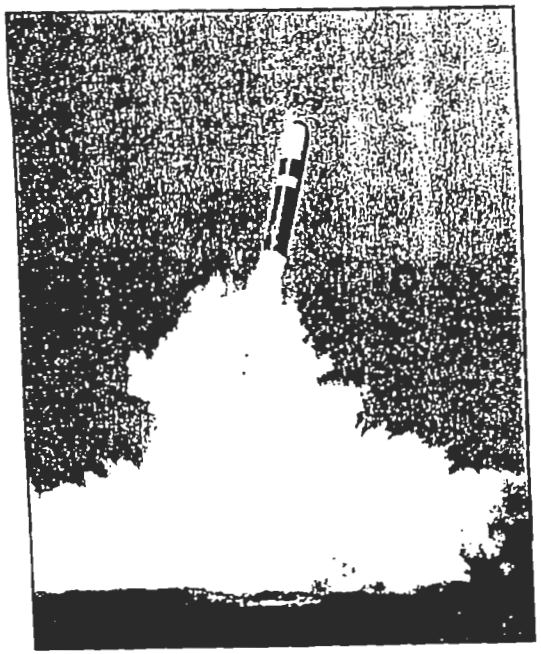
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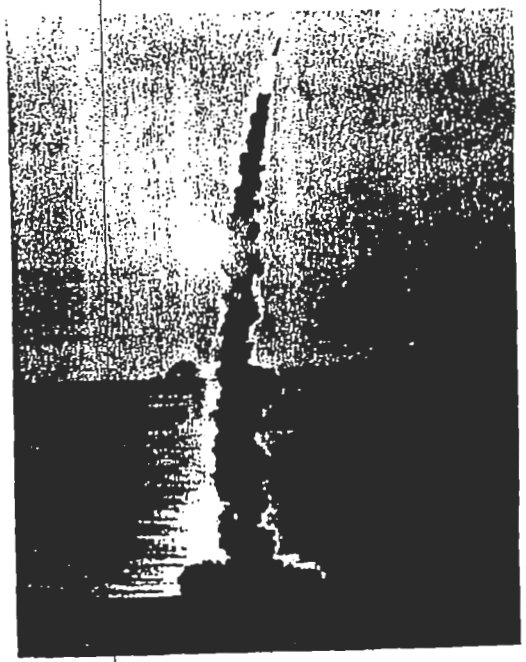
Summary

- RRW POG established and organized
- Study goals, strategy, and scope defined and understood
- Requirements are being defined (MC, STS)
- Design competition underway

RRW



Planning & Assessment Subcommittee Update



9 June 2005

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Status

- **Recommend additional item for Charter**
  - Compile evaluation criteria for POG to select design

- **Subcommittee kickoff late June - early July**
  - Date currently being coordinated

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Program Planning and Cost Control Subcommittee

- Cost report, detailing the resources required to produce and maintain each preferred design through the design's lifecycle
- An acquisition strategy for RRW that fits within the JCIDS process
- A recommendation for the optimal balance of W76-1, W88 and RRW warheads in the SLBM fleet
- Prepare, update and maintain a Joint Integrated Project Plan (JIPP)
- Coordinate, develop, and maintain the Integrated Master Schedule (IMS)
- Prepare, update and maintain the Coordinated Project Summary
- Coordinate the development of Memorandums of Understanding, Memorandum of Agreements, and Inter-Agency Agreements to support development, production, and deployment of RRW

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LANL DESIGN OPTIONS

A-05-243(R)

9 June 2005

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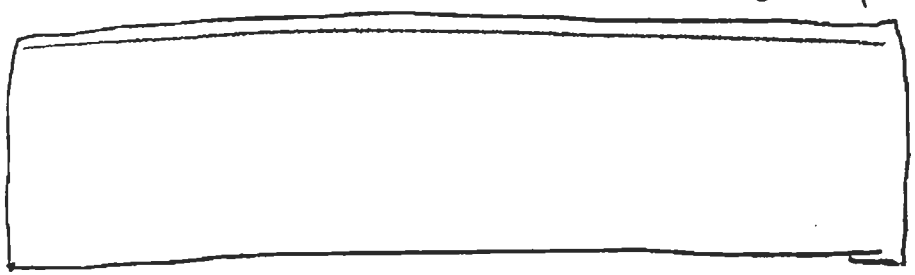
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PRIMARY DESIGN AND CERTIFICATION

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RRW JPOG

June 9, 2005



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RRW Meets Requirements for the Future Nuclear Deterrent

❑RRW must be credibly certified w/o nuclear testing

- ➢Design technology and space selected for certification

[redacted] 1.4(a)(e)

- ➢Use gates and QMU for certification

❑RRW must reduce costs

- ➢Infrastructure costs (factories)
- ➢Manufacturing costs (personnel and processes)
- ➢Maintenance costs (field level repair and rebuild)

❑RRW must be mission flexible

- ➢Multiple missions and delivery platforms

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❑RRW must be used to train new nuclear staff

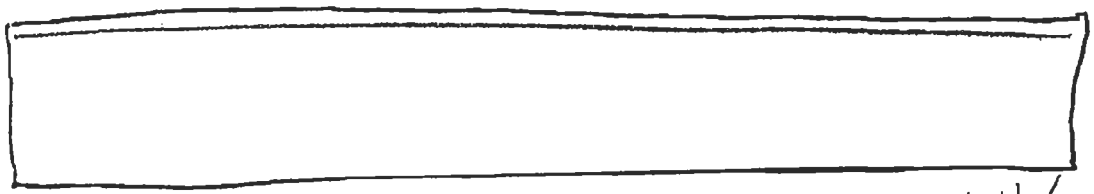
- ➢Judgment is lacking in inexperienced staff

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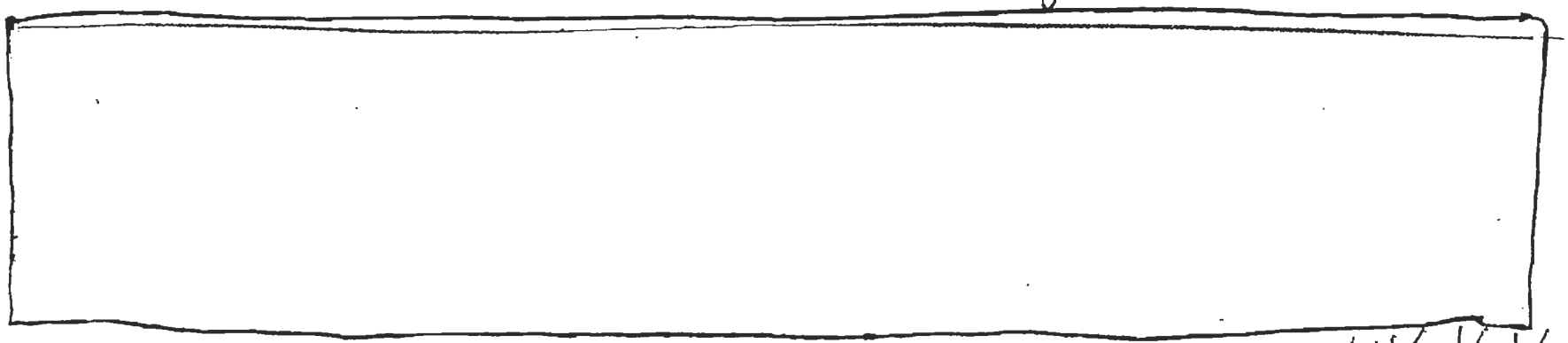
LANL RRW Design Derivation

❑Technology selection for certification

➢Lack of nuclear RRW testing limits technology choices



1.4(a)(e)(g)



1.4(a)(e)(g)

❑Pedigree

➢LANL design by NTS experienced designers with a proven record

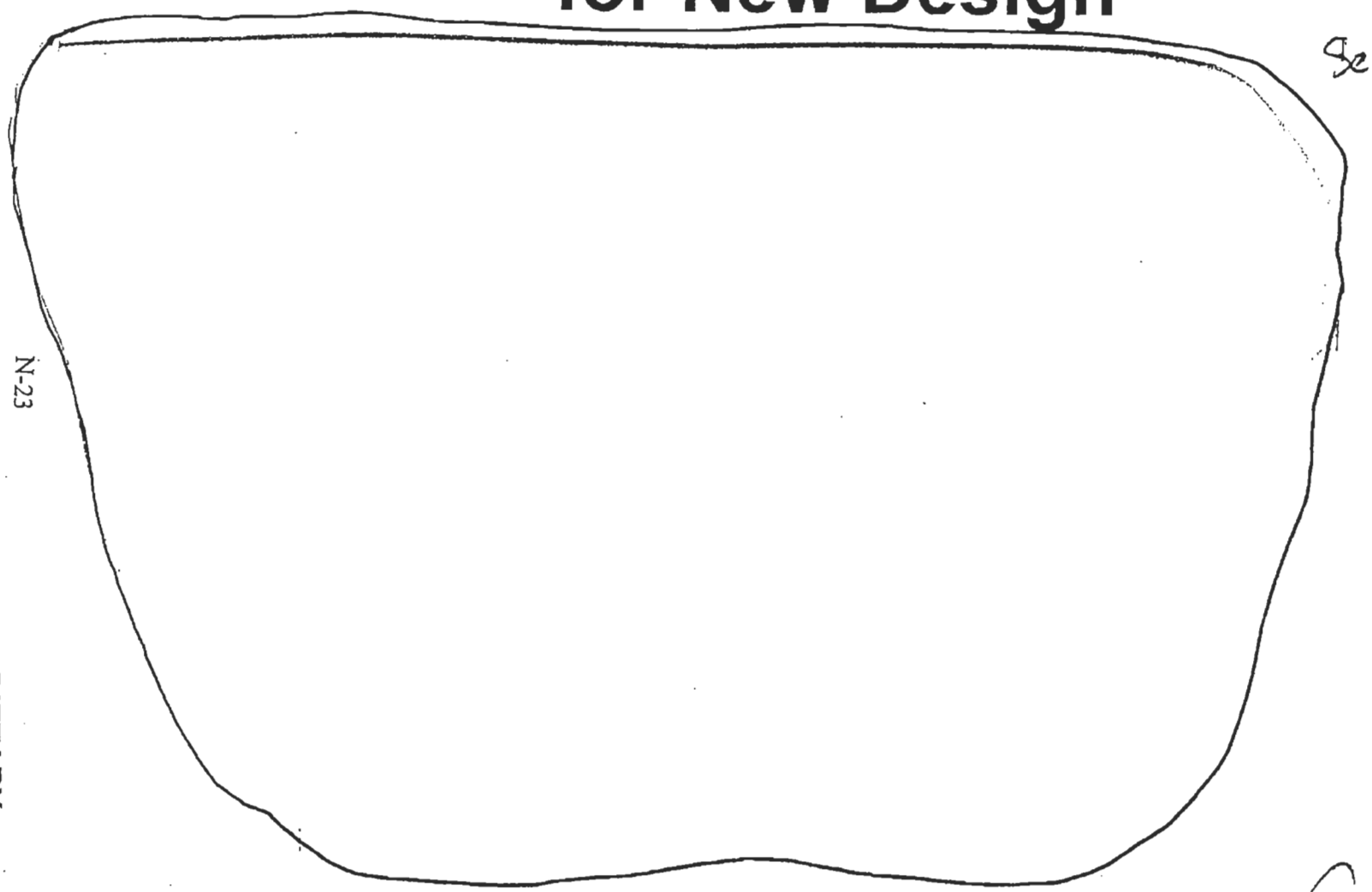
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Calculations are Insufficient for New Design

DOE b(3)

Sec 6.2 RD



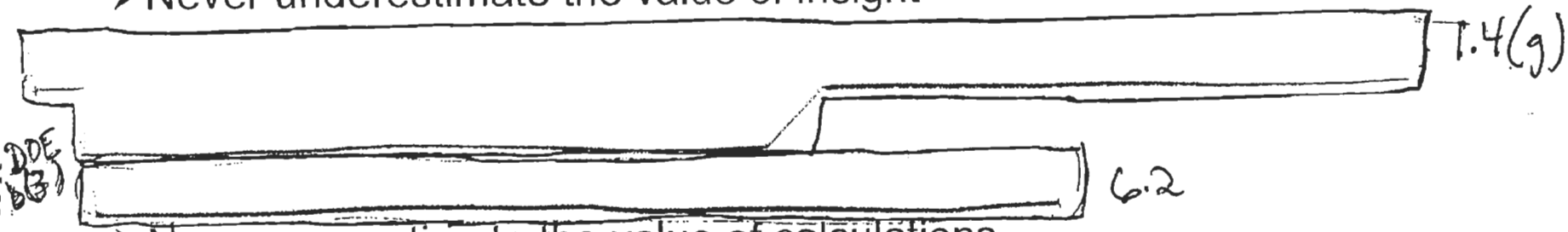
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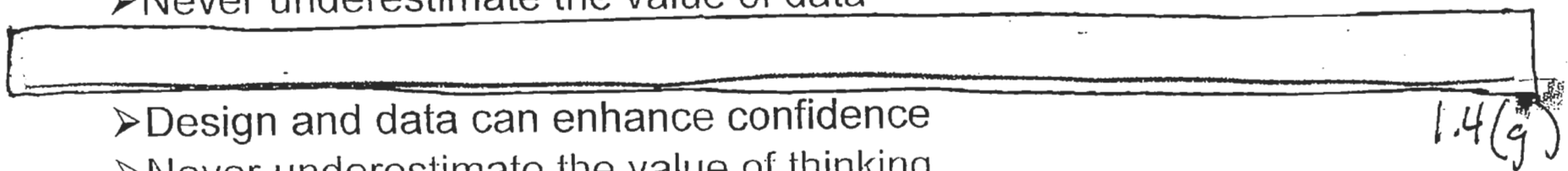
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CALCULATION SUMMARY

- **Computer models can be inferior to physics models**
  - B54 test history fit better by simple physics models
  - Never underestimate the value of insight



  - Never overestimate the value of calculations
- **NTS data + primitive computers are superior to modern computers alone**
  - Never underestimate the value of data



  - Design and data can enhance confidence
  - Never underestimate the value of thinking

SECRET RESTRICTED DATA/CNWDI/PROPRIETARY

LANL RRW Design Derivation

- **Technology selection for certification**
  - [redacted] 1.4(g)
  - [redacted] 1.4(g)
- **Limits to computer simulations**
  - Without experienced designer judgment, calculations are questionable
- **Design for certification without nuclear testing**
  - [redacted] 1.4(g)
- **Pedigree**
  - LANL design by NTS experienced designers with a proven record

~~SECRET RESTRICTED DATA/CNWDI/FRD/NOFORN/ETR~~

~~SECRET RESTRICTED DATA/CNWDI/FRD/NOFORN/ETR~~

Certification by Era

- **Classical era (real kt at NTS)**
  - 1945 to 1992
  - Scientific method
  - Highly optimized designs win cold war
- **Transitional era (derivative kt)**
  - 1992 to 2007
  - Perturbation calculations from specific events
  - SLEPS maintain deterrence but are expensive
- **Future era (calculated kt)**
  - Begin 2007
  - Much improved simulations, maybe predictive
  - General tie to NTS data base, not specific shots
  - Advanced diagnostics for legacy and RRW weapons
  - Designs optimized for 21st century appear

SECRET RESTRICTED DATA/CNWDI/PROPRIETARY

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SECRET/RD

Los Alamos

RRW DESIGN SUMMARY

(Design choices and statistics lead to certifiable weapon)

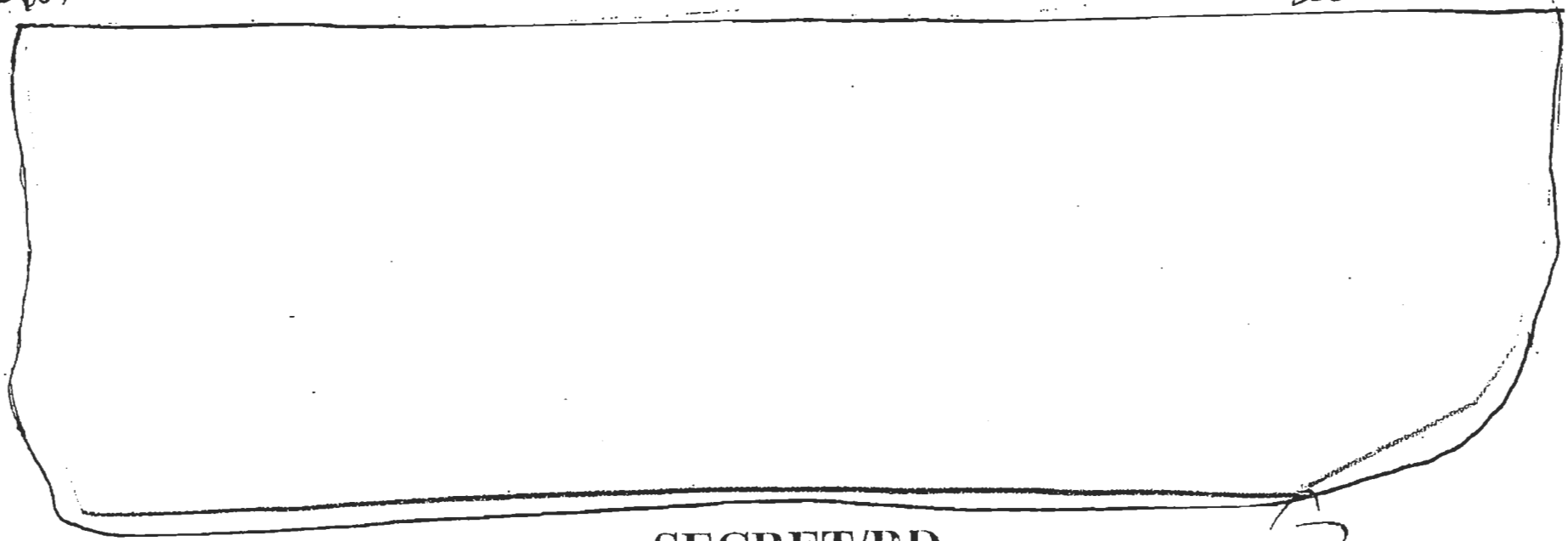
❑Historical precedent guides RRW design

- ➢Technology selection for success without testing
- ➢Lessons from NTS show limits to judgment and calculations

❑Eliminate known problems through design

- ➢Leave the margin for unknown unknowns

DOE b(3) Sec 6.2 RD



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~~SECRET RESTRICTED DATA//CNWDI//PROPRIETARY~~

DESIGN PEDIGREE SUMMARY

- **LANL has successfully met SLBM requirements**
  - 30 year history of successful support
- **LANL designs to SLBM specifications**
  - Not recycled concepts adapted to SLBM use
- **LANL innovations to meet SLBM needs**
  - Stockpiled systems were developed, stockpiled, and maintained
  - [redacted] 6.2 RD
  - RRW is SWPP
- **Design team continuity for the future**
  - Overlap of designers ensures excellence
  - Designers of the future trained on the systems they will maintain

~~SECRET RESTRICTED DATA / CNWDI / FRD / RD / PROPRIETARY~~
~~SECRET RESTRICTED DATA / CNWDI / FRD / RD / PROPRIETARY~~
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LANL RRW DESIGN CONCLUSION

DOE b(3)

6.2 RD

1.4 (c)(g)

➢Keep it simple with respect to options we cannot test

❑Limits to computer simulations

N-45 DOE b(3)

➢Judgment and insight are prerequisites to calculations

6.2 RD

❑Pedigree

➢LANL SLBM design by NTS experienced designers with a proven record

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Radiation Laboratory

Livermore, California

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BY D. R. GILSON. DATE 6-17-94
ADD

HANDBOOK FOR UNITED NATIONS OBSERVERS

PIÑON TEST, ENIWETOK

RECEIPT NO. _____
RECEIPT NO. _____
[illegible] CENTER
[illegible]
AEC NO 7601
BOX NO. 1390

RETENTION CATEGORIES

A. Permanent:
- ____ Deviating from established policy
- ____ Setting precedent for future actions
- ✓ Reflecting unusual sensitivity
- ____ Historical interest
- ____ Subject of litigation

B. Six Years: ____ All others

9-8-77 (Date of review) (Name)

Printed for the U. S. Atomic Energy Commission

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DEDICATION

This handbook is dedicated to Dr. Mark M. Mills who conceived the Pinon Project and developed in detail the initial plan. Dr. Mills lost his life in a helicopter accident at the Eniwetok Proving Grounds on April 6, 1958 while making preparations for the execution of the experiment.

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PREFACE

This report comprises a handbook which was intended to be used by technical representatives from the United Nations Scientific Committee on the Effects of Atomic Radiation during a demonstration of a low fission to fusion yield explosion at the Eniwetok Proving Grounds. The handbook includes the operational concept and detailed technical descriptions of the methods of measurement which were to be used to determine the total energy release and the fission energy release. The total energy release was to be measured by rate of fireball growth measurements, and is described in the section entitled Fireball Determination of Total Yield prepared by Dr. Lewis Fussell of Edgerton, Germeshausen and Grier, Inc. The fission yield was to be determined by a radiochemical method and is described in Chapter III prepared by Dr. Roger Batzel of the University of California Radiation Laboratory.

This demonstration shot, designated Pinon, was cancelled on July 26, 1958. However, because the techniques described here had not been published previously it was considered desirable to publish the handbook.

GERALD W. JOHNSON
Technical Director

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FOREWORD

In 1954 the United States had already begun research to find means of drastically reducing the proportion of fission yield required in the thermonuclear explosion. This was an effort to develop nuclear explosives whose residual radioactivity could be confined more nearly to the area of blast and thermal damage, and to reduce greatly the amount of radioactive fallout which would be created from such explosions and given world-wide distribution. In July, 1956, the United States announced that it had achieved initial success in this program and in test firings had found that, with further development, weapons of drastically reduced fission yield could be produced.

The United States has with high priority continued the development of weapons of greatly reduced fission yield in proportion to total yield. A large portion of the current test series (Hardtack) is being devoted to making possible a material increase in the number of reduced-fission type weapons that can be produced.

On April 25, 1958, the United Nations, on behalf of the United States, offered to nations represented on the U. N. Scientific Committee on the effects of atomic radiation an invitation for their representatives to observe a demonstration of the firing of a weapon of greatly reduced fission yield. This demonstration will provide opportunity for the U. N. Observers to witness the firing of such a device and to make a determination, through instrumentation and laboratory analyses, of the weapon's total and fission yield.

It is the purpose of this handbook to describe briefly the operational procedure to be followed for the U. N. observance, the instrumentation to be used, and the analyses to be made.

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have been derived through correlation of fireball-growth parameters with the total energy-release of fission bombs as determined by radiochemical means. On the other hand, theoretical studies have given the scaling constants in terms of the gamma (ratio C_p/C_v of the specific heats) for air at elevated pressures and temperatures; comparison of the two methods has actually thrown much light upon these characteristics of the medium in regions of strong shock.

It was shown, prior to the first atomic explosion at New Mexico, that the energy release may be expressed by

$$E = K\rho_o R^5 t^{-2} \qquad (1)$$

where R is the radius of the spherical shock wave in an ideal medium, t is the time after the explosion, ρ_o is the atmospheric density, and K is a dimensionless parameter dependent upon the gamma of the medium inside the fireball. This relation was published by its originator, Sir Geoffrey I. Taylor[1], in a pair of articles that also compared the theoretical prediction with the experimental observations obtained during the New Mexico (Trinity) shot of 1945.

The observations obtained for the first several test shots of the USAEC showed that equation (1) was generally not satisfied until the latter phases of visible shock propagation; but that after a preliminary period of deviant growth it did indeed settle down and obey equation (1) for a time interval long enough to permit the empirical evaluation of the parameter K, in terms of the radiochemical yield. From this observation it follows that the gamma of air remains approximately constant for a considerable range of fireball temperatures and pressures.

When the quantities in equation (1) are expressed in CGS units, the first determination based on about six shots was K = 1.740. After a few years it appeared that the value K = 1.709 gave a better fit with the radiochemical data. This value continues to be good to this day, when applied to the prescribed portion of the hydrodynamic-growth curve.

3. Taylor Theory

Taylor considers the total energy release to consist of two parts:

---

[1] G. I. Taylor, Proc. Roy. Soc. 201A, 159, 175 (1950).

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$$\text{the kinetic energy,} \quad K.E. = 4\pi \int_o^R \frac{1}{2} \rho u^2 r^2 \, dr$$

$$\text{and the heat energy,} \quad H.E. = 4\pi \int_o^R \frac{pr^2}{\gamma - 1} \, dr \ .$$

He starts with the equations of motion and continuity and the equation of state of a perfect gas. He determines the boundary conditions in terms of the Rankine-Hugoniot relations, which describe the conditions at the shock front. He finds it necessary to use approximations for these relations. The approximations are excellent as long as the pressures are very large compared with the ambient pressure. He concludes, on page 163, that the total energy release is given in equation (1) and that K is the sum of two integrals, each depending only on gamma.

Two errors may be noted in his derivation. On page 162, his equation 16a, the coefficient $(2\gamma/\gamma + 1)$ is inverted but is corrected in equation 16b. On page 161 a more fundamental error occurs, when he expresses the velocity of sound in air in terms of the variable parameter gamma; he should have used the value $\gamma_o = 1.40$. It turns out that this causes but a small error in the final result. It should also be noted that in calculating the energy release of the New Mexico shot, Taylor assumed an ambient air density of 1.25×10^{-3} g/cc, considerably greater than the true value 1.006×10^{-3}.

Taylor evaluates his integrals by means of step-by-step numerical integration, assuming several different values of gamma. These are summarized in his Table 3, page 180. He also derives some approximate formulae to facilitate these numerical calculations. We have re-stated his integral expressions, using $\gamma_o = 1.40$, and have evaluated them using the approximate methods.

The calculated values of K are found to be:

γ	K (Taylor)	K (re-calculation)
1.20	1.727	1.740
1.30	1.167	1.175
1.40	0.856	0.856

Several sources of data are available, from which the probable magnitude of gamma may be estimated. An estimate is all that can be made,

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since the actual temperatures in the fireball interior can only be surmised; the surface is certainly much cooler, and we can observe only the surface. The published data may be found in the literature.[2,3,4,5] These data are summarized in the curves given in Figure 1. Although there is some scatter to the data, it is clear that gamma goes through a broad minimum, and is of the order 1.2. Thus Taylor's theoretical scaling constant K = 1.740 differs from the experimental value K = 1.709 by only 2 percent, and we use the experimental number in evaluating all USAEC test shots. The energetic equation is, then,

$$E = 1.709 \rho_o R^5 t^{-2} \text{ (ergs)} \quad . \tag{2}$$

In practice the USAEC has measured the fireball diameter, rather than the radius, and has used a different set of units throughout. Expressing D in meters, t in milliseconds, ρ_o in grams/liter, and E in kilotons, relation (2) may be rewritten:

$$E = 1.272 \times 10^{-8} \rho_o D^5 t^{-2} \text{ kilotons} \tag{3}$$

where we use the conversion factor, one kiloton = 4.2×10^{19} ergs.

This conversion factor, although somewhat arbitrary, has been used consistently.[6]

---

[2] J. G. Logan and C. E. Treanor, Tables of Thermodynamic Properties of Air from 3,000° to 10,000°K, Cornell Aeronautical Lab Report BE-1007-A3, January 1957.

[3] J. O. Hirschfelder and C. F. Curtiss, Thermodynamic Properties of Air, II, Naval Research Lab Report CM-472, University of Wisconsin, June 1948.

[4] J. Hilsenrath and C. W. Beckett, Tables of Thermodynamic Properties of Argon-Free Air to 15,000°K, Arnold Engineering Development Center Report AEDC-TN-56-12 (ASTIA AD-98974).

[5] Thermodynamic Properties of Highly Ionized Air, AFSWC-TR-56-35 (ASTIA AD-96303), Kirtland Air Force Base, New Mexico.

[6] S. Glasstone, Sourcebook on Atomic Energy, D. Van Nostrand, 1950.

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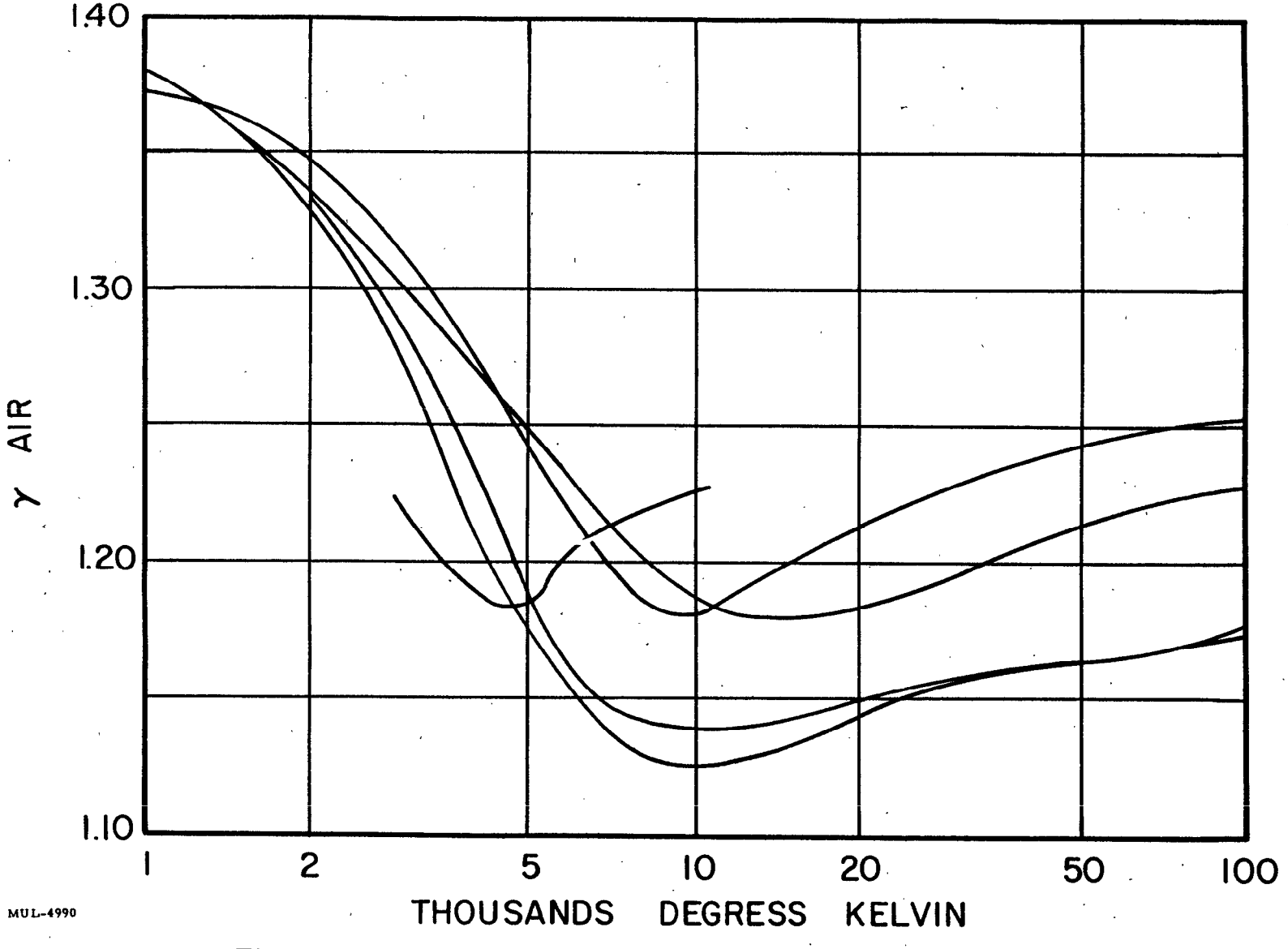


Fig. 1. Specific heat ratio gamma vs temperature for air.

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4. Expected Diameter/Time Curves for Piñon

It has been shown that the energy release from a nuclear explosion in an ideal medium is proportional to D^5/t^2, where D is the diameter of the symmetric shock front, and t is the time since detonation, at which this diameter obtains. In his theoretical derivation Taylor uses a quantity A, which is proportional to $D^{5/2}/t$; similarly we have found it useful to determine a parameter $\phi = D/t^{2/5}$ which is, like Taylor's A, approximately constant for a given shot. The deviations of ϕ from a constant are indicative of extraneous effects (such as varying gamma and also of large masses in the vicinity of the immediate explosion); the constancy of ϕ and the length of the interval over which it is constant lends confidence in the result. Further, a statistical analysis of the scatter of the experimental points in the constant-ϕ region can be used to establish confidence limits for the yield of the explosion.

Figure 2, a log-log plot of the expected diameter-vs-time data for yields of 1, 3, and 10 megatons, shows continuously increasing diameters, and slight deviations from straight lines. These deviations are magnified in the ϕ vs t plot of Figure 3; it is clear that ϕ becomes constant for the interval immediately preceding shock-breakaway, and this interval is used for scaling purposes. After breakaway the shock front is invisible (although it continues to grow with constant ϕ for a while longer), and the fireball itself lags behind. The fireball edges become indistinct and diffuse, and measurements are valueless as far as yield determinations are concerned. An ambient air density ρ_o = 1.15 grams/liter has been assumed in drawing these curves.

The trend of the data, in the early stages prior to constant-ϕ growth, is typical of shots which are exploded with only small amounts of material in the immediate vicinity of the detonation. When large masses must be consumed in the early phases, the growth pattern may be altered drastically; nevertheless it will settle down to the same constant ϕ.

5. Growth into Inhomogeneous Atmosphere

The high-yield nuclear explosion results in a fireball of large physical size. During the period in which yield measurements are to be made the top of the fireball may reach an elevation of about 3,600 ft, where the density of the air is about 90 percent of that at sea level. Thus the fireball

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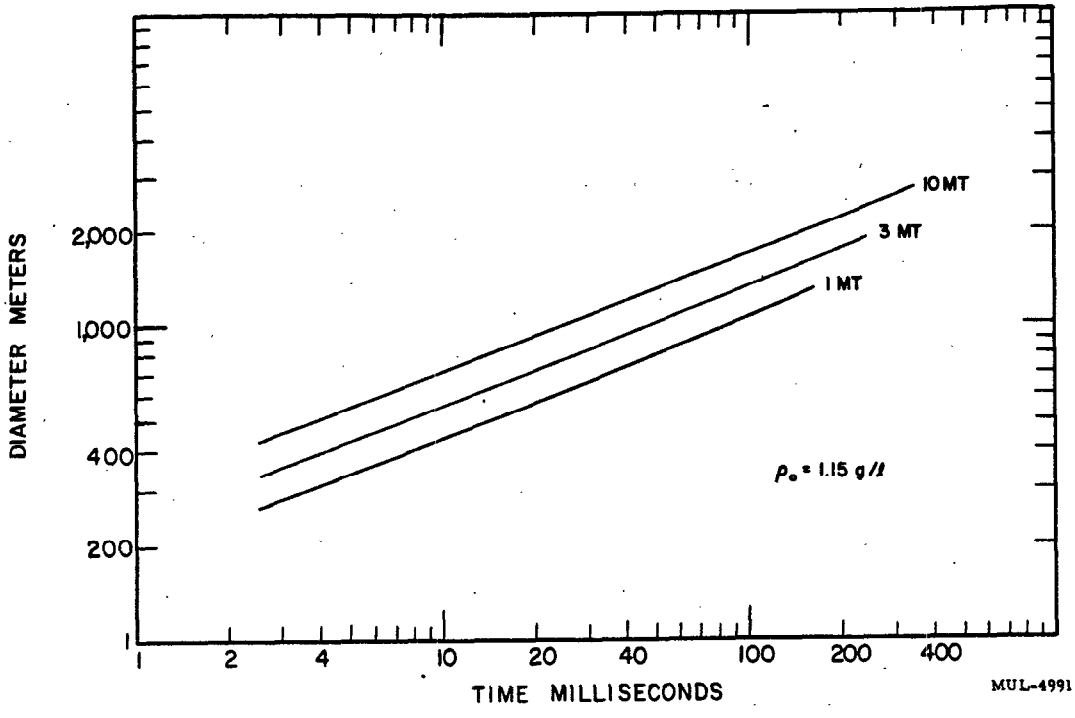


Fig. 2. Fireball growth, diameter vs time – surface shots, ρ_o = 1.15 g/liter.

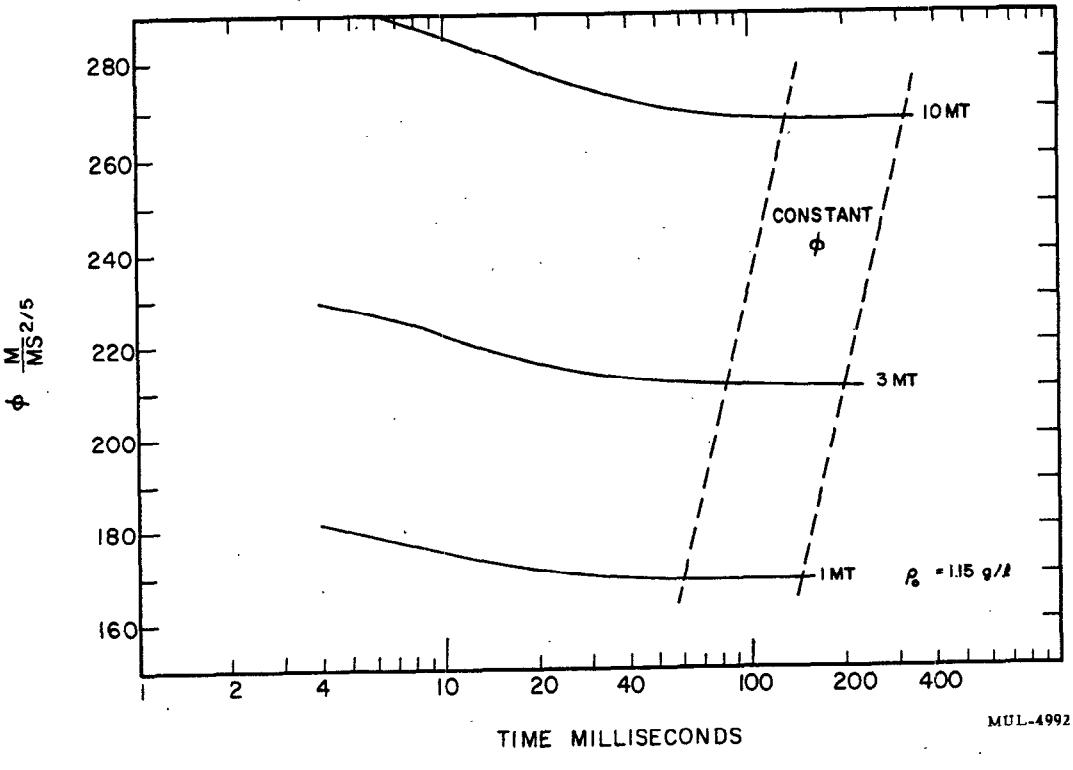


Fig. 3. Fireball growth, ϕ vs time – surface shots, ρ_o = 1.15 g/liter.

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can grow more rapidly, and to a greater extent, in the vertical direction than in the horizontal. The result will be a fireball shaped something like half an egg, rather than a perfect hemisphere.

The appropriate air density is that occurring at the center of the fireball area, such that half the area is above, and half below, the chosen altitude. For a hemisphere the altitude for center-of-area occurs at one-half the radius; we apply the same criterion to the distorted fireball, and use a different value of air density for each frame that we measure.

This effect does not alter the validity of the scaling laws; it simply introduces another step that must be taken in the analysis of the data and requires detailed data on the variation of air density with elevation.

6. Ground Reflection Effect

The effect of the rigid water surface must be considered for the Piñon shot, which is to be detonated within a few feet of sea level. The acoustic impedance of water is about 150,000 grams/cm^2/sec, whereas that of air is only 44. The result is that very little energy goes into the water; instead it is reflected almost perfectly back into the fireball and reinforces the shock front that was directed upward initially. The fireball becomes a nearly perfect hemisphere (excluding the effects of the inhomogeneous atmosphere which were just discussed), and the hemisphere represents half of a fireball having twice the apparent energy. Thus the factor $F = 0.50$ is introduced into the scaling equation, and the total yield for a surface burst is given by

$$E = 0.5\, K \rho_o D^5 t^{-2} \quad . \tag{4}$$

7. Measurements Required

It has been shown that four quantities must be measured in order to determine the total fireball energy release:

a) diameter of the fireball,

b) time after burst at which the measured diameter obtains,

c) air density (specific gravity) as function of altitude, and

d) ground-reflection factor.

The diameter of the image of the fireball, formed by the camera lens upon the film, will be measured in the analysis procedure. In order to relate this image to the size of the fireball itself, it is necessary to determine the

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magnification factor of the optical system. This factor is equal to the ratio

$$\frac{\text{Distance, camera to plane perpendicular to optic axis containing the fireball diameter}}{\text{Lens focal length}}$$

Since the camera is operated at a slightly tilted angle, τ, the desired optic-axis distance equals the horizontal (ground) distance multiplied by cos τ. It is thus necessary to measure the horizontal distance, L, the focal length, f, and the angle of tilt, τ; once measured these quantities will remain constant for all frames exposed in a given camera. The USAEC measurements are each good to about 0.2 percent, and facilities will be provided to check them to something like 1.0 percent.

The time scale, relating each exposed frame to the time after detonation, will be determined from timing marks placed upon the film while the camera is being exposed. These marks will establish the time after detonation to better than 0.2 percent, and the observer-check will also be good to 0.2 percent.

The air density requires measurements of barometric pressure, temperature, and relative humidity, all three as functions of altitude. These quantities will be measured by means of weather balloons, released on Eniwetok Island shortly before detonation, which will telemeter the meteorological data to the ground. An independent measurement of the ground-level data will be made at the Control Point adjacent to the photo tower on Parry Island; this will utilize a Cenco mercury barometer and a standard sling-psychrometer. These instruments will be available for check-reading by the Observers, prior to and at shot time. From these readings the air density at ground level may be determined to a precision of about 0.2 percent; check values at various altitudes may be derived from this number through the use of the standard atmospheric data (such as those adopted by the NACA), to better than 0.5 percent.

The ground-reflection factor will be taken as equal to 0.50, and no measurements are contemplated.

8. Precision of Measurements

In addition to the individual measurement errors described above, one expects a reading error during the analysis of the films. For each frame

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encountered infrequently. For the Piñon shot the images will be approximately hemispherical. The fireball edge will be only moderately sharp, because of scattering in the 20-mile photographic path; scattering may also result in poor exposures of low contrast. Furthermore, natural clouds will probably obscure portions of the fireball, since it will grow to a considerably greater height than the normal low-lying cloud cover. These factors introduce the necessity for exercising some degree of judgment in measuring the fireball diameters.

The orientation of the film on the comparator stage is such that the images will appear to be on their sides, with the horizon vertical. The image of the selected picture is centered, making use of the micrometers and the rotational adjustment, so that the base of the fireball coincides with the vertical diameter of the circular grid pattern. It will undoubtedly be necessary to adjust the illumination for both stages, and in some cases to switch the upper stage light on and off to aid in locating the fireball edge in reference to the grid.

The observer can usually bracket the average diameter quickly by noting the greatest and the least circles of contact. These limits can be narrowed by running the eye around the intermediate circles, finally interpolating to arrive at a best estimate of the average or effective diameter. Experience and practice are required to make this determination quickly and consistently, and without undue fatigue. It is always best, in our experience, to have each picture measured by several persons; in the event of disagreement between them a short discussion usually suffices to reach a joint reading agreeable to everyone.

Before moving the film to read another frame, it will be necessary to measure with the micrometer the distance from the film-speed mark to the trailing sprocket hole. These measurements only need to be precise to about 0.03 inches, or one-tenth of a frame, and a visual estimate may suffice instead of a measurement. They will enable the calculation of the time for the particular picture.

25. Calculation of Total Yield

Measurements and calculations are best worked out in tabular, systematic form. We usually record all measurements and calculations on vellum, which may be reproduced in any desired quantities easily and

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quickly. One sheet of paper will summarize the magnification parameters:

horizontal distance: L
camera tilt: τ
optic-axis distance: $L \cdot \cos \tau$
camera focal lengths: f
camera magnifications: $L \cdot \cos \tau / f$, and
the Hauser magnifications for each objective.

Another sheet will summarize the meteorological data, and will tabulate air density ρ_z and the fifth-root of the density, as functions of altitude; the fifth-root data will also be plotted on graph paper against altitude.

Four additional sheets, one for each film, will tabulate for each picture measured:

the time and image diameter,
the corresponding object diameter, D
the parameter $\phi = D \cdot t^{-2/5}$, and also
$\phi \rho_z^{1/5}$.

Tables giving $t^{-2/5}$ as a function of t, will be provided to aid these last two determinations, and the density chosen will correspond to an altitude equal to one-fourth the diameter.

The computed parameter ϕ will be plotted against log (time) to determine the interval over which it is essentially constant. Finally an average figure will be determined for $\phi \rho_z^{1/5}$, over the indicated time interval and over all four cameras; this value will be raised to the fifth power and multiplied by $\frac{1}{2} \times 1.272 \times 10^{-8}$ to obtain the total energy release in kilotons.

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CHAPTER III

RADIOCHEMICAL DETERMINATION OF FISSION YIELD

A. THEORY

The fission yield of a device can be measured by radiochemical techniques by using macroscopic tracer of sufficient amount to allow a measure of the fraction of total debris collected in a sample. From this bomb fraction and the absolute number of fissions collected in a sample, the total fission yield can be measured.

The bomb fraction tracer is placed in such a manner as to insure that the material will mix completely with the fission products and be distributed uniformly with the fission products throughout the post-shot cloud. Aircraft equipped with units designed to collect representative samples of debris on filter papers are flown through the cloud.

The samples are removed from the aircraft by remote handling techniques, the radiation levels measured and the samples packaged and returned to the laboratory for dissolution and analysis. Fractions of the solution containing the filter paper are then taken for measurement of the bomb fraction and the absolute number of fissions. Uranium in the form of U_3O_8 is used as the tracer. Molybdenum 99 has been chosen as the fission product to be determined. The total fissions are given by

$$\text{Total fission} = \frac{\text{Initial uranium}}{\text{Uranium in sample}} \times \text{Fissions in sample.}$$

Since one megaton TNT equivalent is defined as 10^{15} calories and the prompt energy per fission is 179 Mev, 1.45×10^{26} fissions are equivalent to one megaton.[10]

B. TECHNIQUES

PREVIOUSLY DELETED

1. Bomb Fraction Tracer

The bomb fraction tracer to be used is [redacted] uranium partially depleted in U^{235} in the form of uranium oxide (U_3O_8). The uranium oxide has a bulk density of about 2.5 g/cc and will be packaged in approximately 100-pound containers.

---

[10] R. B. Leachman, Phys. Rev. 87, 444 (1952); R. B. Leachman and W. D. Schafer, Can. J. Phys. 33, 357 (1955); and S. R. Gunn, H. G. Hicks, H. B. Levy, and P. C. Stevenson, Phys. Rev. 107, 1642 (1957).

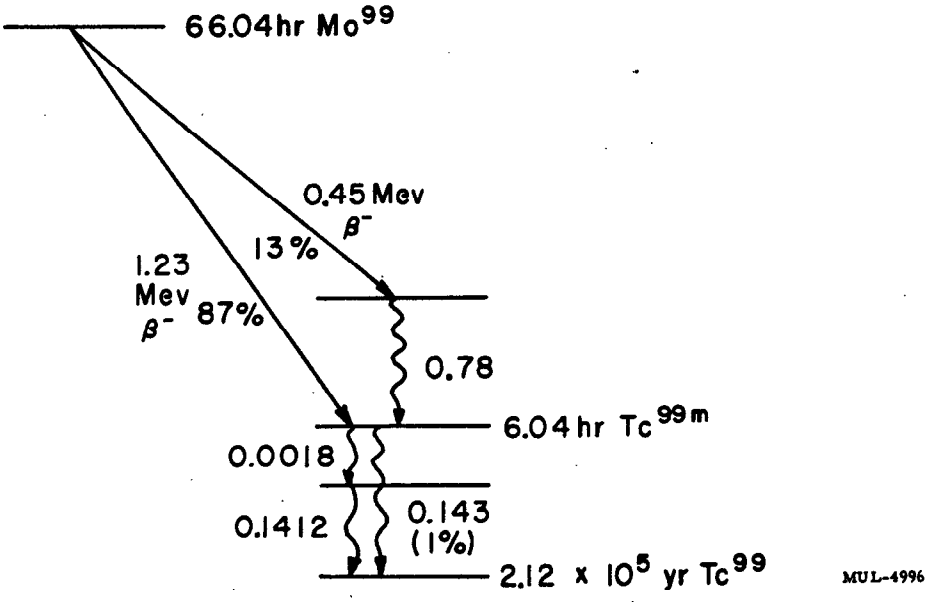
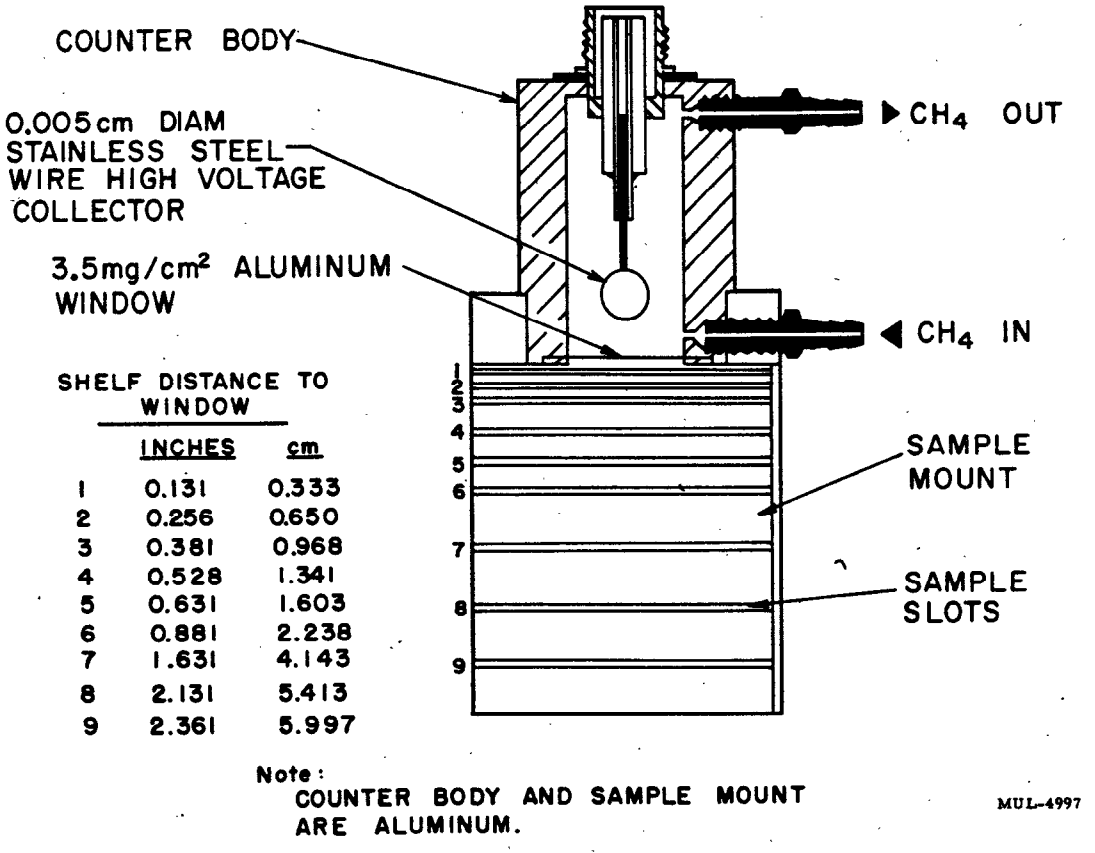


Fig. 14. Decay scheme of Mo^{99}.



SHELF DISTANCE TO WINDOW

	INCHES	cm
1	0.131	0.333
2	0.256	0.650
3	0.381	0.968
4	0.528	1.341
5	0.631	1.603
6	0.881	2.238
7	1.631	4.143
8	2.131	5.413
9	2.361	5.997

Note:
COUNTER BODY AND SAMPLE MOUNT ARE ALUMINUM.

Fig. 15. Beta proportional counter and sample mount.

Table II. Fission Yield of Mo^{99} from U^{235} as a Function of Bombarding Neutron Energy

Energy (Mev)	0	0.95	4.85	14.2
Percent fission yield	6.14[a]	6.10[a]	5.45[a]	5.17[b]

[a] J. Terrell, W. E. Scott, J. S. Gilmore, and C. O. Minkkinen, Phys. Rev. 92, 1091A (1953).

[b] J. Terrell, W. E. Scott, J. S. Gilmore, and C. O. Minkkinen, Item 55-136 (Presented at the American Physical Society Meeting, Sept. 3, 1953, Albuquerque, New Mexico).

The beta proportional counters (Figure 15) used to determine Mo^{99} disintegration rates are calibrated using Pb^{210} - Bi^{210} - Po^{210} samples of known disintegration rates obtained from the National Bureau of Standards. Pertinent data for each standard are provided by the National Bureau of Standards. These Ra D+E samples are counted in the same position relative to the counter as the Mo^{99} is to be counted. A thin ($7mg/cm^2$) aluminum absorber is placed close to the counter to absorb any α radiations from Po^{210} and β radiations from Pb^{210}. The observed counting rate is corrected for absorption by air gap, absorber, and 3.4 mg/cm^2 aluminum counter window, back-scattering from the Pd-Ag mount, and self-absorption of the PbO_2 electro deposit (see Appendix III for sample calculation). The corrected counting rate is divided by the known absolute disintegration rate of the standard sample to give the efficiency, i.e., the solid angle of the counter for a weightless sample mounted on a weightless mounting.

Previously, a carrier-free sample of Mo^{99} was prepared and a measured portion evaporated carefully on a thin Mylar (organic polymer) film supported on a frame. Another measured portion of the active solution was added to a known amount of inactive molybdenum in solution as Mo(VI). The solution was well mixed and heated to 90°C for 15 minutes. Then $PbMoO_4$ was precipitated, washed twice with water, once with acetone, and dried for one hour at 130°C. After cooling to room temperature, samples of varying weight were prepared on thin aluminum dishes. All samples were mounted on thick aluminum holders and counted in the proper geometry. Figure 16 shows the results of these measurements.

One may now correct the observed Mo^{99} counting rate for the effects of self-scattering, back-scattering, self-absorption, and absorption due to air gap and counter window in the same manner as for the Ra D+E standard. The aliquot mounted on Mylar is taken as a good approximation to a weightless sample on a weightless backing.

Given the absolute disintegration rate of a sample of Mo^{99} separated from the bomb debris, the following sequence of calculations is performed;

1. The disintegration rate is extrapolated back to the time of detonation, using the known half-life of 66.04 hours.

2. The number of disintegrations per unit time at the time of detonation, is converted into atoms of Mo^{99} through the relationship

$$\text{atoms of } Mo^{99} = \frac{\text{disintegration rate x half-life}}{\ln 2}$$

3. The number of fission events giving rise to the derived number of molybdenum atoms is derived through the relationship

$$\text{numbers of fissions} = \frac{\text{atoms of } Mo^{99}}{\text{fission yield of } Mo^{99}}$$

The short half-life of Mo^{99} may render impossible the direct confirmation of the above series of measurements. However, it has been our experience that the 282 day Ce^{144} is also an excellent fission indicator and will give results similar to those from Mo^{99}. The determination of Ce^{144} must wait for at least two weeks after the detonation to allow the Ce^{143} to decay sufficiently for accurate determination, hence our choice of Mo^{99} for this demonstration.

b. Chemical Separation Procedure. Radiochemical analysis for Mo^{99} is routinely performed using carrier, i.e., a known amount of inert molybdenum added to the active material. Once isotopic exchange has been attained, chemical separations performed on milligram amounts of added carrier molybdenum will serve to separate the radio-molybdenum in exact proportion. When the carrier material is completely purified from extraneous activities, it is precipitated in weighable form and weighed to determine the fraction recovered.

Tracer and carrier molybdenum ions exchange readily in hydrochloric acid medium if nitrate is present to insure the complete conversion of all

molybdenum to Mo(VI).

A measured aliquot of the sample solution is added to a measured aliquot of previously analyzed ammonium molybdate solution. After thorough mixing, the solution is brought to pH 5 with ammonium acetate-acetic acid buffer, and 0.1 M $Pb(NO_3)2$ solution is added to precipitate the molybdenum lead molybdate. The sample is centrifuged and the supernatant is discarded. The precipitate is dissolved in 9 M HCl and the solution is poured through a column packed with anion exchange resin (Dow Chemical Company Resin "Dowex A-1"), previously treated with 9 M HCl. When all the active solution has passed through, the molybdenum is located in an adsorbed band at the top of the resin column. The following solutions are then passed in turn through the column to remove impurities: 10 milliliters (ml.) of 9 M HCl; 10 ml. of 0.1 M HCl; 1 ml. H_2O; 5 ml. of 3 M NH_4OH; 1 ml. H_2O. The molybdenum is then removed from the resin by passing through 15 ml. of 4 M HNO_3. A few drops each of sodium tungstate solution and silver nitrate solution are added to the eluate and the solutions mixed; then sufficient dilute hydrochloric acid is added to precipitate the added silver as silver chloride. The solution is digested in a hot-water bath to coagulate the mixed precipitates of tungstic acid and silver chloride and the precipitates are centrifuged off and discarded. The tungsten and silver precipitations are repeated. A small quantity of a solution containing Fe^{+3}, La^{+3}, Te^{+4} and Zr^{+4} is then added to the supernatant and precipitated with NH_4OH at pH 10 or higher for further decontamination. The precipitate is rejected. More Fe^{+3} and La^{+3} are added to the supernatant (which is ammoniacal) and the resulting precipitate rejected. The supernatant solution is then acidified with acetic acid to pH 5 and 0.1 M $Pb(NO_3)_2$ solution is added to precipitate the molybdenum as lead molybdate. The precipitate is washed with water and acetone and dried.

The dry precipitate is transferred to a weighed aluminum dish, the dish and contents are re-weighed, and the precipitate fixed in place by a few drops of diluted lacquer. The weight of recovered lead molybdate is determined by difference. The small dish is fastened with adhesive tape to a support suitable for insertion into the counting equipment and is counted once or twice daily for several days. The lacquer must be thoroughly dry before the counting is started, since the lacquer solvent exerts a pronounced effect on the counting rate.

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This separation procedure for molybdenum has been described by Gunn, Hicks, Stevenson and Levy, Physical Review, 107, 1642 (1957). Analyses are run in triplicate or quadruplicate to minimize experimental errors.

c. Treatment of Data. Each individual counting rate measurement is subject to two corrections. After recording an event, a counting instrument is insensitive for a period known as the "dead time", which we may represent by the symbol τ. Then if there are R events per unit time, the instrument is insensitive for a time $R\tau$ and operative for a time $1-R\tau$ in each unit time. The true counting rate then is $R \times 1/(1-R\tau)$. In the instruments used the dead time τ is so small (5 to 6 μ sec) that at ordinary counting rates the correction may be neglected. There is also a correction (due to the "background" rate of the counter) that is the counting rate in the absence of the sample. Background may be due to cosmic radiation, radioactive contamination of the counter, or electronic noise in the amplifier circuits; it is considered to vary only slowly with time. A measurement of the background rate made shortly before or after the measurement of the sample counting rate will yield a number which is subtracted from the measured rate to give the true counting rate of the sample.

The observed corrected counting rate for a pure sample of Mo^{99} will decrease exponentially with a half-life of 66.04 hours. The activity of the Tc^{99} and Tc^{99m} daughters activities are 99 percent adsorbed by the air gap and counter window and thus can be neglected. The counting rate for each sample can be extrapolated back to the time of the detonation to give an "initial rate" R_o.

The calculations are then as follows:

Let

$$y = \frac{\text{weight } PbMoO_4 \text{ recovered}}{\text{weight of Mo as } PbMoO_4 \text{ added as carrier}}$$

$$a = \frac{\text{volume of aliquot taken for analysis}}{\text{volume of total sample}}$$

f_{SSA} = proper ordinate of Figure 16

t = mg/cm^2 air gap + counter window

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$$\mu = \frac{0.693}{42} \frac{cm^2}{mg}$$ absorption coefficient for β radiation of Mo^{99}

g = fraction of disintegrations detected by counter as measured with Ra D+E standard

$$\text{disintegration rate of } Mo^{99} = \frac{R_o e^{\mu t}}{y \cdot a \cdot f_{SSA} \cdot g} = N\lambda$$

where N = Mo^{99} atoms

$$\text{and } \lambda = \frac{\ln 2}{66.04 \cdot 60} = 1.749 \times 10^{-4} \text{ min}^{-1}$$

$$\text{fissions represented by sample, f} = \frac{N\lambda}{1.749 \times 10^{-4} \times \text{fission yield of } Mo^{99}}$$

d. Calculation of Fission Yield. Given the above information on number of fissions and amount of uranium in the sample the fission yield can be calculated as follows:

$$\text{Fission yield in megatons} = \frac{\text{initial uranium x fissions in sample}}{\text{uranium in sample x } 1.45 \times 10^{26} \text{ fissions/megaton}}$$

e. Fission Ratio Determination. With the results of the fireball measurement of total yield and the radiochemical measurement of fission yield, the fission fraction can be calculated as shown:

$$\text{Fission ratio} = \frac{\text{Fission yield in megatons}}{\text{Total yield in megatons}}$$

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temperature latitudes with a few months. Thus we will consider materials with half lives of a few months as potential long range hazards. Among the fission products, Sr^{90} is the classic example of a worldwide hazard and Sr^{89} is an example of a long-range but not worldwide hazard.

In the following estimates of amounts of radioactive materials formed, experimental numbers were used where available. For neutron capture in ground and air it was assumed that one neutron per 150 Mev total yield was emitted by the weapon, (taken equivalent to 2×10^{26} neutrons/MT). For an air burst all neutrons were assumed to be absorbed by nitrogen, while for a surface burst half are taken to be captured in ground and half in air. Activities produced in ground are assumed to be mixed in the fireball and fall out like fission products.

The following potentially hazardous radioactive materials have been considered.

A. Half lives longer than 1 year:

Sr^{90}: [redacted] DoE b(3)

[redacted] At 5% one obtains .16 Megacuries Sr^{90} per Megaton fission (Mc/MT fission). Sr^{90} is discussed in order to compare clean and fission weapons.

C^{14}: Formed in 95% of all air captures. This gives:

.02 Mc/MT for air burst

.01 Mc/MT for surface burst.

Co^{60}: May be produced in up to ~.1% of neutron captures in ground, leading to 10^{23} atoms/MT for surface burst. [redacted] DoE b(3)

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Taking this higher figure we obtain

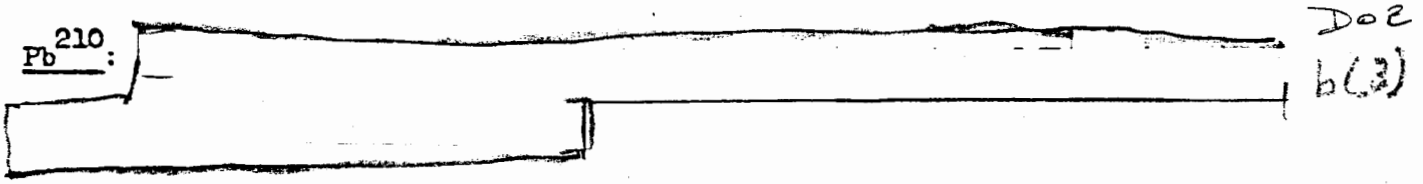
.12 Mc/MT.

Fe^{55}: Produced in ~.5% of ground captures or 5×10^{23}/MT for surface burst.



.4 Mc/MT.

Pb^{210}:



3 curies/MT.

Cl^{36}: For surface detonation over sea water will produce about 60c/MT.

Ca^{41}: For surface detonation on typical ground will produce about 4c/MT with a maximum of about 240c/MT for a surface burst on limestone.

Cs^{134}: For surface detonation on typical ground may be formed in ~.01% of ground captures of 3×10^{3}c/MT.

B. Half lives less than one year:

Sr^{89}: Formed in about 5% of U^{235} fissions or 30Mc/MT fission, but only in about 3% of fissions for standard two stage weapons.

Ca^{45}: Formed by neutron capture in ground -- in about .05% of captures in average ground, .2% in concrete and 3% in limestone. For detaonations on concrete we have

.27 Mc/MT.

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Note that the production of Ca^{45} will vary markedly with the Ca content of the surface on which the weapon is detonated.

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W^{185}: [redacted] In addition about 25Mc of W^{181} may be expected but this is probably appreciably less hazardous than the W^{185}.

P^{32}: May produce from ~.05% of neutron captures in average ground. This leads to about .5 Mc/MT but may vary considerably with phospherous content of soil.

Fe^{59}: From iron in weapons have produced 4×10^{22} atoms per MT or .2 Mc/MT.

Da
b(

Po^{210}: [redacted]

The above figures are summarized in Table I:

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It will be seen that all the clean radioactive products are unlikely to be a worldwide hazard for energy releases, $\lesssim 10^5$ megatons. Thus they are probably of no great concern in the present rate of testing weapons and we shall consider only the hazard associated with their use in wartime, i.e., we assume that the radioactivity is injected over a short period of time.

Of the long lived isotopes produced by clean bombs it is likely that C^{14} is the most hazardous. Estimates may be made from the radiocarbon studies. Libby takes a carbon inventory averaged over the earths surface of .45 gm/cm^2 of carbon in the biosphere and atmosphere (a similar number would obtain for atmosphere plus part of biosphere plus top of ocean). This gives 2.25×10^{18} gm of available carbon on the earth's surface. If from NBS Handbook 52, we take maximum permissable amount of C^{14} in body at 25μc[1] (for large populations) and body mass as including about 10 kg C; then the maximum permissable ratio of C^{14}/to C in biosphere is 2.5×10^{-3} μc C^{14} per gram of C. This corresponds to a total C^{14} production of 5.6×10^3 Mc or a yield of 3×10^5 Mt.

Measurements exist on the increase in C^{14} activity due to weapons tests. On the above scale, about 50 Mt of neutrons have been released to the air. We would predict from this a production of 1 Mc of C^{14} and an increase of C^{14} in atmosphere and biosphere of about .5 $\mu\mu$c/gm. This corresponds to .02 disintegrations per sec per gm of C, which is about 7% of the natural rate. An increase of about 10% in the C^{14} concentration in the atmosphere has been observed -- thus indicating that our estimates are reasonable.

It may be noted that detonation of 3×10^5 Mt could increase the C^{14} content of the atmosphere by a factor 10^3 above natural levels. Conceivably an increase of this magnitude could produce non-physiological hazards such as perturbation of weather by increasing conductivity of the air. However it appears

[1]Note that this and most subsequently quoted levels would increase the radiation level in a critical organ by a factor 10 above the natural background.

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unlikely that this particular effect could be important. The natural C^{14} in the air contributes at the most (at sea level over water) only 10^{-4} of the ion pairs which produce the air conductivity. Thus increase of the C^{14} levels by 10^3 would increase air conductivity by only $\lesssim 10\%$. Much larger variations occur naturally, with altitude, and air over earth vs. air over water.

For Sr^{90}, Anderson and Langham have summarized fission megatons required to produce hazardous levels of Sr^{90}. For a world average, 3×10^4 Mt fission would lead to about 1 μc/kgm Ca or 3×10^3 Mt to .1 μc/kgm Ca.

DOE
b(3)

(Which number is most similar to the 25 μc C^{14}?) Variability of Sr^{90} distribution and capture has led some to recommend that these yields should be divided by about a factor 10 to have a safe level of Sr^{90} everywhere (outside the locality of detonation).

The chief hazard of Co^{60} may lie in its use as a trace element of importance to some organisms or simply as a general source of γ radiation from the ground. One may estimate the latter danger as follows: Suppose the Co^{60} is deposited uniformly over the earth surface where it has a mean life against removal by weathering of ~ 1 year. If a dose, to exposed flesh, of 1.5 r in one year is considered roughly comparable to the large population figures, we estimate (from figure 9.120 of Effects of Nuclear Weapon) that this corresponds to about 10 curies/mi^2 or a total yield of about 2×10^5 Mt. This indicates that Co^{60} could be directly a hazard comparable to the inevitable C^{14}, and its production should be kept low in clean weapons. It may be argued that a mean life of 1 year against weathering is much too large, but on the other hand there will no doubt be concentrations in the fallout.

An estimate may also be made on the hazard of ingested Co^{60}. If one takes $10 \mu gm/cm^2$ of available Co on earth surface, 5×10^{-4} gm of Co^{60} in a person, a maximum permissable amount of Co^{60} in body of .3 μc, and assumes equilibrium between Co^{60} and ordinary Co in biosphere he finds 2.5×10^5 Mt required to produce a hazardous level. However, in view of the apparently poor absorption of Co and its short effective half life (as reported in Handbook 52) it would appear unlikely that equilibrium can be established in the Co^{60} lifetime. Nevertheless it would appear wise to devote further study to Co^{60}.

The remaining long lived isotopes of table I appear less hazardous than C^{14}, by an order of magnitude or more. Fe^{55} appears harmless unless there are efficient mechanisms for direct consumption of Fe. This conclusion can be reached by considering Fe^{55} in equilibrium with available Fe in the same manner that Sr^{90} (relative to Ca) was treated by Libby. Pb^{210}, Cl^{36}, Ca^{41}, Cs^{134} are created in too small quantities to be hazardous.

Of the short lived isotopes, Ca^{45} and W^{185} appear most worthy of attention. P^{32} does not appear as hazardous as Ca^{45} -- because of its shorter half life.

The hazard of Ca^{45} may be compared with that of Sr^{89} since these have similar half lives. It may be expected that 1 curie of Ca^{45} produced by a bomb is about as hazardous as 10 curies of Sr^{89}. This factor 10 is arrived at through the following factors. Sr is discriminated against relative to Ca in entry into human bones by a factor (10). The energy of the Ca^{45} β^- is (1/6) the energy of the Sr^{89} β^-. The half life of Ca^{45} is (3) times that of Sr^{89}. This longer half life will give the Ca^{45} a longer time to reach bones so that perhaps an added factor (2) advantage is obtained. $10 = (10)(1/6)(3)(2)$.

Thus the hazard due to Ca^{45} production as in Table I is about twice that due to Sr^{89} from a 5% fission weapon. For a similar detonation over Limestone these figures give Ca^{45} predominating over Sr^{89} by a factor of about 30.

A quantitative comparison between damage due to Sr^{89} and Sr^{90} is difficult to make. Probably energy deposited by Sr^{89} in bones is $\approx$ 10% of the Sr^{90} energy.. However it is delivered 100 times as fast. It appears that under adverse conditions the Ca^{45} formed in a 5% fission weapon could be more damaging than the Sr^{90}.

W^{185} is, an isotope deserving of considerable attention.

If one assumes that W behaves like Mo in the body, then the saving feature appears to be that only 2×10^{-4} of the ingested W^{185} (Mo) will reach bone, the critical organ, (NBS Handbook 52). The energy per W^{185}

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No. 1 of 17 copies. Series A.

4125

LOS ALAMOS SCIENTIFIC LABORATORY
MEMORANDUM

UNIQUE DOCUMENT # SAB20009083000O

November 9, 1954

TO: Distribution

FROM: George I. Bell

SUBJECT: CONTROL OF RADIOACTIVE CONTAMINATION FROM LARGE YIELD WEAPONS.(U)

SYMBOL: T-649

The characteristics have been investigated of some large yield weapons [redacted] it is felt that one must use a fuel which contains a substantial amount of Li^6 and which is compressed by an efficient implosion system. Two detailed calculations have been made. However, no general survey has been made to explore the yield as a function of implosion system and Li^6 concentration.

[redacted]

CRM FILE CC DOE 38387 b(3)

DOE b(3)

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW
1ST REVIEW-DATE: 1-30-96
AUTHORITY: DADC DADC, ADD
NAME: P.A. Cox Jr. Hqtr
2ND REVIEW-DATE: 1-31-96
AUTHORITY: ADD
NAME: P.A. Cox Jr.
DETERMINATION (CIRCLE NUMBER(S))
(1) CLASSIFICATION RETAINED
2. CLASSIFICATION CHANGED TO: ____
3. CONTAINS NO DOE CLASSIFIED INFO
4. COORDINATE WITH: ____
5. CLASSIFICATION CANCELLED
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7. OTHER (SPECIFY): ____

RESTRICTED DATA

This document contains Restricted Data as defined in the Atomic Energy Act of 1954. Unauthorized disclosure subject to administrative and Criminal Sanctions.

96SA20B000009

Two graphs have been prepared to show how this [redacted] compares with fission product activity. They are somewhat simplified in that the involvement of many half lives and gamma energies has been ignored and only the dominant (and more or less average) decay [redacted] has been considered. The predominant gamma ray energy is 0.41 Mev, somewhat less than that for an average fission product decay.

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[redacted]

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[redacted] the graphs. There it is indicated that for periods up to about two weeks, and in areas where contamination from fall-out might otherwise be heavy enough to be practically significant, [redacted] On the other hand, [redacted] after a period of five or six weeks, [redacted]

DOE b(3)

George I. Bell

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Enclosures

1. A Memo to Members of Initiator Committee, from K. T. Bainbridge about Minutes of Meeting of July 6, held in Room B-212, dated July 14, 1944. (Doc # A-83-013-3-26, SAA200061180000) 3 pages
    a. A document about the summary of Neutron Bd. Measurements, Appendix A, 1 page
    b. A Document about Po Delivery Schedule As of April 12-14, 1944, Appendix B, 1 page
    c. A document about Neutron Yields of Initiator Assemblies Fired to July 4, 1944, by G. Farwell, Appendix C 1page
    d. A Letter to Dr. Norris Bradbury about the United States suspending Nuclear Weapons Tests, by Dwight D. Eisenhower, dated August 22, 1958. (Doc # SAB200090810000) 1 page
    e. A letter to Brig. General A. T. Starbird from Darol Froman about Finding a Document # T-1009 rough draft and T-1026 by George Bell, dated May 29, 1958. (Doc # TAD-2333, SAB200090810000) 5 pages

2. A document about Long Range Fallout from Clean Weapons by George Bell, dated May 5, 1958. (Doc # Rough Draft T-1009, SAB200090820000) 11 pages

3. A Memo from George I. Bell about Control of Radiation Contamination from Large Yield Weapons, Symbol: T-649, dated November 9, 1954. (Doc # T-649, SAB200090830000) 7 pages

4. A letter to Dr. Gaelen Felt from John S. Malik about the attached document on Gamma Radiation Nuclear Weapons, dated June 15, 1959. (Doc # J-13, SAB200090840000) 2 pages

5. A document from Darol Froman on Some Ideas about the LASL Thermonuclear Program, dated June 1951. (Doc # TAD-262, SAC200075530000) 11 pages

6. A document (Rough Draft) from N. E. Bradbury, H. A. Bethe, D. K. Froman, J. C. Mark, L. W. Nordheim, E. Teller on Los Alamos Laboratory Proposed Thermonuclear Program, dated June 7, 1951. (Doc # ADWD-272, SAC200015540000) 6 pages

7. A document from Los Alamos Scientific Laboratory of The University of California, written by Harris Mayer, with Illustrations by George Gamow on Daddy Pocketbook, dated January 25, 1950. (Doc # LAMS-1066, SAB200083670000) 22 pages

8. A document of Engineering Instruction by L. R. Hoschek, dated May 25, 1989. (Doc # PX-675) 57 pages

9. A document on 12-44-1 Incident Events Board by R. L. Burke, dated May 17, 1989. (No Document Number) 37 pages

10. A document on ES&H/WM Safety survey Report of W48 Serial Number 4902 HE Removal and Packaging Operations at the USDOE Pantex Plant by P.D. Stewart & R. L. Benson, dated December 7, 1992.(No Document Number) 13 pages

23. A document by Lawrence S. Germain about A Brief History of the First Efforts of the Livermore Small-Weapons Program, dated January 2, 1991. (Doc # LA-11404, SAC20008691000) 30 pages

24. A document by Lawrence S. Germain about A Review of the Development of Los Alamos Gnats and Tsetses Before the 1958 Test Moratorium, dated January 2, 1991. (Doc # LA-11749, SAC200086920000) 22 pages

25. A document by Steven G. Hallett about Modification and Testing of the MC4043 Jettison Cutter Component of the B90 Weapon System, dated January 1991. (Doc # MHSMP-91-04) 18 pages

26. A document from D. Gilson about FY91 through FY93 Process Development Plans and Budgets, Advanced Development Manufacturing Development, dated September 1990. (Doc # MHSMP-90-35, SAB200050050000) 40 pages

27. A document by W. H. Chambers, H. F. Atwater, J. T. Caldwell, W. E. Mauldin, N. Nicholson, T. E. Sampson, G. M. Worth and T. H. Whittlesey about MRV Verification by On-Site Inspection from Los Alamos Scientific Laboratory of the University of California, dated November 1970. (Doc # LA-4577, SAA200057740000) 66 pages

28. A document by W. H. Chambers, H. F. Atwater, J. T. Caldwell, P. E. Fehlau, C. N. Henry, J. H. Jett, W. E. Kunz, W. E. Mauldin, N. Nicholson, A. A. Robba and T. E. Sampson about Nuclear Weapon and Materials Detection, dated July 1972. (Doc # LA-4919, SAA200057750000) 115 pages

29. A document about Progress Report Number Eight of the Research Division of the Los Alamos Project, dated April 1, 1945. (Doc # LAMS-233, SAB200087010000) 16 pages

30. A Report by H. A. Bethe about Recommendations of the Initiator Advisory Committee, dated May 1, 1945. (Doc # LAMS-237, SAB200087030000) 15 pages

31. A Progress Report Number eleven of the Gadget Physics Division of the Los Alamos Project, dated June 15, 1945. (Doc # LAMS-262) 77 pages

32. A Progress Report Number ten of the Gadget Physics Division of the Los Alamos Project, dated May 15, 1945. (Doc # LAMS-252, SAB200087020000) 77 pages

33. A Progress Report Number nine of the Gadget Physics Division of the Los Alamos Project, dated April 15, 1945. (Doc # LAMS-236, SAB200087050000) 68 pages

34. A document by Samuel K. Allison about Relation between the Various Activities of the Laboratory, dated December 23, 1946. Volume C (Doc # LA-1006, SAB200087060000) 144 pages

35. A Document about Monthly Progress Report of the Chemistry and Metallurgy Division, dated June 1, 1945. (Doc # LAMS-261, SAB200087070000) 38 pages

36. A Document about The Story of the Los Alamos Laboratory, NO DATE, (Doc # A-83-002 19-4, SAC200117690000) 40 pages

37. A Quality Report of Pinellas Quality Assurance Inspection Agency, dated March 1971. (Doc # AL0035) 8 pages

38. A document about Minutes of G-7 Administration Meeting dated on March 27, 1945. (Doc # A-84-019-45-8; SAC200104750000) 4 pages

39. A Memo to R. W. Dodson from C. L. Critchfield about Record Form for Service Initiators, dated July 2, 1945. (Doc # A-84-019-17-4, SAC200103760000) 1 page

40. A document by John M. Haschke and Joseph C. Martz about Interim Storage of Excess Plutonium: An Assessment of Options, dated June 17, 1993. (Doc # LA-12624-MS, SAA200075580000) 56 pages

41. A document by J. M. Haschke and J. C. Martz about Storage of Plutonium Extracted from Weapons, dated March 12, 1993. (Doc # LA-12551-MS, SAA200075570000) 56 pages

42. A document by W. B. Leslie and R. W. Dietzel about Titanium Hydride-Potassium Perchlorate: A Spark Insensitive Pyrotechnic Material, dated October 1974. (Doc. # SAND74-0220, SAC200102400000) 40 pages

43. A Memo to NESD from J. David Finley about Nuclear Explosives Safety Study Report, dated August 23,1994. 1 page

44. A document from John A. Wheeler about Nature of Project Matterhorn, dated March 3, 1953. (Doc # SAC200088270000) 15 pages

45. A document about History of the Mark 5 Bomb, from Information Research Division/3434, dated March 1967. (Doc # SC-M-67-545, SAB200090970000) 26 pages

46. A document about History of the MK 5 Warhead from the Information Research Division, 3434, dated May 1967. (Doc # SC-M-67-546, SAB200090980000) 56 pages

47. A Progress Report Number six of the Gadget Physics Division of the Los Alamos Project, dated January 15, 1945. (Doc # LAMS-198, SAB20008700000) 63 pages

48. A document of Minutes of the Thirty-first Meeting of the Theoretical Megaton Group by R. W. Goranson, dated June 18, 1952. (Doc.# TMG-M31, SAA200070030000) 54 pages

49. A document of Minutes of the Thirty-second Meeting of the Theoretical Megaton Group by R. W. Goranson, dated June 28, 1952. (Doc # TMG-M32, SAA200069710000) 13 pages

50. A document of Minutes of the Thirty-third Meeting of the Theoretical Megaton Group by Frank C. Hoyt, dated July 18, 1952. (Doc # TMG-M33, SAA200067920000) 8 pages

51. A document of Minutes of the Thirty-fourth Meeting of the Theoretical Megaton Group by Rolf Landschoff, dated July 29, 1952. (Doc # TMG-M34, SAA200069730000) 7 pages

52. A document of Minutes of the Thirty-fifth Meeting of the Theoretical Megaton Group by Rolf Landschoff, dated on August 13, 1952. (Doc # TMG-M35, SAA200069740000) 9 pages

53. A document of Minutes of the thirty-sixth Meeting of the Theoretical Megaton Group by Rolf Landschoff, dated August 27, 1952. (Doc # TMG-M36, SAA200069760000) 9 pages

54. A document of Minutes of the Thirty-seventh Meeting of the Theoretical Megaton Group by Rolf Landschoff, dated September 3, 1952. (Doc # TMG-M37, SAA200069770000) 5 pages

55. A document of Minutes of the Thirty-eighth Meeting of the Theoretical Megaton Group by Rolf Landschoff, dated September 17, 1952. (Doc # TMG-M38, SAA200069780000) 11 pages

56. A document of Minutes of the Fortieth Meeting of the Theoretical Megaton Group by Frank C. Hoyt, dated on October 22, 1952. (Doc # TMG-M40, SAA200069790000) 6 pages

57. A document of Minutes of the Forty-first Meeting of the Theoretical Megaton Group by Rolf Landschoff, dated November 12, 1952. (Doc # TMG-M41, SAA200069800000) 4 pages

58. A document of Minutes of the Forty-third Meeting of the Theoretical Megaton Group by Frank C. Hoyt, dated on November 26, 1952. (Doc # TMG-M43, SAA200069810000) 6 pages

59. A document by Tim Neal about Adapt and SWPP from Los Alamos, dated October 21, 1997, (Doc # SAC200129130000) 6 pages
    a. Memo to WPD:JC from Patricia E. O'Guin about Supplemental AL Workload Planning Guidance Information, dated February 18, 1997. (Doc # SAC200129140000) 9 pages
    b. Memo to WPD:CKK from Kathleen A. Carlson about Albuquerque Workload Planning Guidance 98-0 Transmittal, dated on January 7, 1998. (Doc # SAC200129150000) 30 pages

60. A document by R. B. Craner about Final Development Report for the B61-7 Bomb, dated January 15, 1992. (Doc # SAND85-0474, RS3140/92/00001, SAA200034780000) 41 pages

61. A document by D. N. Bray about Interim Development Report for the B61-6, 8 Bombs, dated March 3, 1989. (Doc # SAND88-2986, RS5111/89/00009, SAA200034790000) 88 pages

62. A document by Scott M. Bowen, Phyllis L. Baca, Loretta F. Olivas, Carmen G. Geoffrion, Joseph L. Thompson and Charles M. Miller-LANL. Wataru Goishi, Bradley K. Esser, Jesse W. Meadows, Neil Namboodiri, David K. Smith and John F. Wild- LLNL about Nevada Test site Radionuclide Inventory, 1955-1992, dated September 26, 1994 (Doc # LA-CP-94-0226, SAC200122500000) 36 pages

63. A document of Minutes of the Twenty-fourth Meeting of the Theoretical Megaton Group by R. W. Goranson, dated April 9, 1952. (Doc # TMG-M24, SAA200069650000) 6 pages

64. A document of Minutes of the Twenty-fifth Meeting of the Theoretical Megaton Group by R. W. Goranson, dated April 16, 1952. (Doc # TMG-M25, SAA200069660000) 8 pages

65. A document of Minutes of the Twenty-sixth Meeting of the theoretical Megaton Group. Dated on April 29, 1952. (Doc # TMG-M26, SAA200069670000) 12 pages

66. A document of Minutes of the Twenty-seventh Meeting of the Theoretical Megaton Group by R. W. Goranson, dated on May 7, 1952. (Doc. # TMG-M27, SAA200069680000) 12 pages

67. A document of Minutes of the Twenty-eighth Meeting of the Theoretical Megaton Group by R. W. Goranson, dated May 14, 1952. (Doc # TMG-M28, SAA200069690000) 7 pages

68. A document of Minutes of the Twenty-ninth Meeting of the Theoretical Megaton Group by R. W. Goranson, dated May 28, 1952. (Doc # TMG-M29, SAA200069700000) 7 pages

69. A document of Minutes of the Thirtieth Meeting of the Theoretical Megaton Group by R. W. Goranson, dated June 10, 1952. (Doc # TMG-M30, SAA200070020000) 8 pages

70. A letter to Mr. Phillip G. Seamster from G. L. Dittman about Update to LLNL Pit Temperature for Storage and Containment Failure Conditions, dated June 2, 1994. (Doc # CODT-94-0304, SAC200132140000) 5 pages

71. A document about nuclear Materials Strategic Reserves, Program Management Plan, (Doc # SAC200132130000) 14 pages

72. A letter to Dr. Sussholz from jc about Detonations in air the Neutrons are Captured in Nitrogen, (Document # J-13-317) 2 pages

73. A memo to Distribution from George Bell about Comparison of Worldwide Due to C^{14}, and Fission Products, dated May 27, 1958. (Document # T-1026, SAB200090850000) 7 pages

74. A letter to Brig. General A. D. Starbird from Herbert F. York about Some Preliminary Estimates concerning Clean Tactical Bombs, dated July 11, 1957. (Doc # SAA200070650000) 9 pages

75. A memo to Norris Bradbury from Edward Teller about the Meeting of the Tech Board concerning the Future Laboratory Program, dated July 28, 1950. (Doc # ADWD-169, SAB200085530000) 1 page

76. A memo to Division Leaders and Assistant Directors from N. E. Bradbury about Attached Draft Memo Covering a Revised Definition of the Technical Associate Directors, dated March 6, 1951. (Doc. # SAB200085540000) 1 page

77. A memo to Assistant and Associates Directors, Division Leaders, Department Heads, Business Manager, and C. L. Tyler from N. E. Bradbury about Technical Associate Director's Responsibilities, dated March 6, 1951. (Doc # DIR-DRAFT) 4 pages

78. A memo to ADWD, Leaders of? ? E, J, F, T, and W Divisions, Chairman, Fission Weapon Development Committee from Darol Froman about Request for Data on Effort and Program Information, dated March 22, 1951. (Doc # TAD-218) 2 pages

79. A document about A Separate Thermonuclear Division from Darol Froman, dated March 20, 1951. (Doc # SAB200085580000) 5 pages

80. A letter to Chairman Gordon E. Dean from Edward teller about concerning future of the Thermonuclear Program, dated April 20, 1951. (Doc # ADWD-260, SAB200085590000) 2 pages

81. A document about A New Site for Thermonuclear Development, dated April 20, 1951.(Doc # ADWD-261) 13 pages

82. A document about Partial Statement Made by Hans Bethe at Princeton Meeting, dated June 16-17, 1951. (Doc # SAB200085620000) 1 page

83. A document to N. E. Bradbury from Gordon Dean about discussing the Status At the Los Alamos PD. (Doc # SAB200085630000, NR S-107 2616372 GR492) 4 pages

84. A memo to Edward Teller from N. E. Bradbury about Responsibilities as Assistant Director for Weapon Development, dated September 24, 1951. (Doc # SAB200085640000) 1 page

85. A memo to N. E. Bradbury from Edward Teller about Comments on Draft Memo of March 6, 1951, dated March 7, 1951. (Doc # SAB200085550000) 1 page

86. A memo to Norris E. Bradbury from Lothar W. Nordheim about Comments on the Organization of the Thermonuclear Work, dated March 23, 1951. (Doc # ADWD-218, SAB200085570000) 2 pages

87. A letter to Dr. J. Robert Oppenheimer from N. E. Bradbury about confirming their Tentative Arrangement, dated June 1, 1951. (Doc # DIR-625, SAB200085600000) 2 pages

88. A memo to Darol Froman from N. E. Bradbury about the Princeton Meeting, dated June 6, 1951. (Doc # DIR-626, SAB200085610000) 1 page

89. A memo to Technical Council Members from Edward Teller about the Super Bomb and the Laboratory Program, dated October 13, 1949. (Doc # ADWD-2-7, SAB200085650000) 5 pages

90. A memo to Members of the Technical Council from J. H. Manley about the Future Laboratory Program, dated October 13, 1949. (Doc # TAD-73, SAB20008566) 5 pages

91. A letter to Dr. John H. Manley from Edward Teller about the Two Distinct Models of the Booster that will be tested of the Feasibilities of Thermonuclear Reactions dated December 13, 1949. (Doc # ADWD-2-, SAB200085670000) 3 pages

92. A letter to Dr. Luis Alvarez from Edward Teller about Radiation Laboratory asking for Help, dated February 8, 1950. (Doc # ADWD-2, SAB200085680000) 1 page

93. A memo to Carson Mark from Hans Bethe about Calculations Concerning the super Weapon, dated June 2?, 1950. (Doc # LAB-T-202, SAB200085690000) 4 pages

94. A document about The Need and Philosophy of Fixing upon a Thermonuclear Development Program, dated March 15, 1951. (Doc # SAB200085700000) 3 pages

95. Notes for Darol Froman by S. Ulam about Some of the Important Projects Necessary for a Rational Thermonuclear Program. (Doc # SAB200085710000) 1 page

96. A Rough Draft from N. E. Bradbury, H. A. Bethe, D. K. Froman, J. C. Mark, L. W. Nordheim and E. Teller, dated June 7, 1951. (Doc # SAB200085720000) 6 pages

97. A memo to C. L. Tyler from N. E. Bradbury about Los Alamos Scientific Laboratory Thermonuclear Program, dated July 13, 1951. (Doc # DIR-643, SAB200085730000) 2 pages

98. A document from Darol Froman about Some Ideas about the LASL Thermonuclear Program, dated June 12,1951. (Doc # TAD-262, SAB20008574000) 11 pages

132. A memo to R. S. Warner, Jr. from H. W. Russ, Subject: Unknown, dated November 12, 1946. (Doc # A-84-019 17-5, SAC200103950000) 2 page

133. A memo to Harlow W. Russ from Marshall G. Holloway about a memo of 12th of December to E. Jette, dated December 16,1945. (Doc # A-84-019 17-5, SAC200103960000) 1 page

134. A letter to Commanding General of Manhattan Engineer District from R. S. Warner, Jr. about Little boy Procurement Program, dated October 23, 1946. (Doc # A-84-019 17-5, SAC200103970000) 2 pages

135. A letter to Dr. Eric Jette from E. E. Wilhoyt, Jr., Subject: Unknown, dated November 1, 1946. (Doc # A-84-019 17-5, SAC200103980000) 1 page

136. A memo to DP-21 (J. Smith, 903-6723) from Charles J. Beers, Jr. about Nuclear Explosive Safety Study of the B53 Mechanical Disassembly Operations at the USDOE Pantex Plant, dated May 27, 1994. 3 pages

137. A memo to RADM Charles J. Beers, Jr. from NESD about Nuclear Explosive Safety Study Report, dated January 3, 1994. 99 pages

138. A list of records to Jette–Morrison, dated July 2, 1945. (Doc # SAC200088280000) 37 pages

139. A document by Wataru Goishi, Bradley K. Esser, Jesse W. Meadows, Neil Namboodiri, David K. Smith and John F. Wild, LLNL, Livermore, CA & Scott M/ Bowen, Phyllis L. Baca, Loretta F. Olivas, Carmen G. Geoffrion, Joseph L. Thompson and Charles M. Miller, LANL, Los Alamos, NM about Total Radionuclide Inventory Associated with Underground Nuclear Tests Conducted at the Nevada Test Site, 1955-1992, dated September 26, 1994. (Doc # LA-CP-94-0222, SAC200122510000) 294 pages

140. A memo to Richard Contreras from H. R. Leos about FL Container Packing Checklist, Appendix 3, for Existing Pits Visual Inspection Checklist Amendments to Existing Pits Received from Rocky Flats, dated October 1, 1997. (Doc # SAC200133330000) 5 pages

141. A letter to Mr. John R. Kirby from J. C. Yarbrough about Model FL Container Sunlight Controls, dated August 10, 1997. (Doc # 192834, SAC200133340000) 5 pages

142. A letter to Gerald L. Dittman from Steven G. Hallett regarding Thermal Modeling, dated July 28, 1997. (Doc # 192891, SAC200133350000) 2 pages

143. A Special Task Group Report-Beryllium Substitute Materials for BE and BEO in Nuclear Weapons, Volume II, Impact on United States Department of Energy National Defense Programs of Proposed Department of Labor (Occupational Safety and Health Administration) Beryllium Standards, dated May 2, 1978. (Doc # SAA200118380000) 3 pages

144. A letter to James R. Nicks from W. F. Weston regarding Beryllium Requirements and Scrap Projections, dated December 14, 1984. (Doc # 84-RF-3511, SAA200118390000) 3 pages

145. A memo to Ken Sprankle from Richard J. Jiacoletti regarding Beryllium Forecasts and Sustainability Estimates, dated December 26, 1985. (Doc # POD-SAA200118400000) 2 pages

146. A letter to Albert E. Whiteman from J. E. Kinzer regarding Beryllium Five-year Projection, dated December 10, 1985. (Doc # 85-RF-3366, SAA200118410000) 3 pages

147. A letter to T. C. Jones from Seymour Sack regarding SRD Report "Beryllium Supply Updated", dated July 21, 1980. (Doc # SAA200118420000) 4 pages

148. A letter to R. E. Batzel from T. C. Jones regarding Beryllium Metal Costs, dated September 11, 1980. (Doc # SAA200118430000) 4 pages

149. A memo to Mr. Michael Q. Guy from J. E. Hockett regarding Response to your TWX of October 3, 1980, regarding brush Wellman Letter and ALO Proposed Beryllium Program, dated November 3, 1980. (Doc # WX-5-80-630, SAA200118440000) 4 pages

150. A letter to Major General J. K. Bratton from R. D. Baker regarding the LASL Position on Future Availability of Beryllium and Beryllium Oxide, dated August 2, 1979. (Doc # ADNSP/100, SAA200118450000) 7 pages

151. A document About B52 Flying Alert over Goldsboro, N. C. on operation Coverall with two? Weapons Experienced ruptured wing Fuel Tank, Broke up in Flight, and crashed. Bombs were torn from Bomb Bay by Violet aircraft Maneuvers, dated January 24, 1961. (Doc # SAC20117770000) 2 pages

152. A document about Lightning/Nuclear Weapon Accident and Incident Reported by FC/DASA in the Period from Early 1961 to February 1968, dated February 25, 1969. (Doc # RS-1515, SAC200117740000) 10 pages

153. A letter to Field Command and Directors from W. Lee Hancock regarding Weapon Debris from Thule Accident returned to AEC, dated June? (Doc # WDW:PRS (S145-68), SAC200117780000) 2 pages

154. A memo to distribution from J. G. Marsh regarding Classification Guidance, Greenland B-52 Weapons Accident, dated February 26, 1968. (Doc # SAC200117730000, 3414 NA, File 16.b) 6 pages

155. A letter to Dr. Norris about the future of the Los Alamos Scientific Laboratory, dated August 14, 1956. (Doc # SAB200144950000) 3 pages

156. A document by Raymond Pollock about A Short History of the U.S. Nuclear Stockpile: 1945-1985, dated January 2, 1991. (Doc # LA-11401, SAB200115710000) 30 pages

157. A document by Joseph S. Howard II and Edward I. Whitted about The Future of Non-Strategic Nuclear Forces. Are these Capabilities Still Needed? Dated April 30, 1991. (Doc # LA-12063-MS, SAC200057210000) 74 pages

158. A document by Joseph S. Howard, Edward J. Palanek, John L. Richter, Richard R. Sandoval, Frank L. Smith, Richard H. Stolpe, CDR Larkin E. Garcia and LTC L. Warren about Modular Weapon Systems and Insertable Nuclear Components, A Compendium of Requirements, Technology, Applications, and Utility, dated September 1983. (Doc # LA-9866-MS, SAB 200090150000) 127 pages

159. A memo to Mr. Oppenheimer from C. S. Smith and I. C. Schoonover about Gun Fabrication-lan-Supplement to Document Dated June 13, 1945, dated June 28, 1945. (Doc # LA-4000,REV.7, 9/94, SAB200115990000) 4 pages

160. A memo to Steve Yan from J. W. Liebenberg about Introductory Words on H1501 (A) Tests, dated February 14, 1992. (Doc # SAC200108720000, NWSSGR 92-1) 10 pages

161. A document to Col. D. J. O'Connor from H. T. Season, Jr. about? Product Change Proposal Support, dated October 13, 1995. (Doc # SAB200086430000) 2 pages

162. A document about B57 Retrograde alternation Proposal, dated April 3, 1992. (Doc # SAC20008945000) 4 pages

163. A memo to Gene Grewis from C. C. Burks about Nuclear Safety of B57-1/2. B61-0/1/2during Logistics Operations, dated April 3, 1992. (Doc # SAC20008946000) 3 pages

164. A rough draft about Technical Manual-Nuclear Weapons Retrofit Order ALT 914, dated April 27, 1992. (Doc # NWSSGR 92-2, SAC200108730000) 15 pages

165. A letter to H. T. Season from C. A. Yarnall about Final Product Change Proposal (PCP) No. 3-92, dated May 18, 1992. (Doc # SAC20008948000) 6 pages

166. A rough draft by T. P. Seitz, E. E. Ives, and H. T. Season regarding B57 Special Study Report, dated September 21, 1992. (Doc # RS5115/92/00016, SAC200089470000) 35 pages

167. A document by H. A. Bethe about Analysis of Joe-4, dated September 11, 1953. (Doc # T-527, A-89-038 29-30, SAB200088600000) 49 pages

168. A document about FY91 through FY93 Process Development Plans and Budgets, Weapons Systems Development, dated September 1990. (Doc # MHSMP-90-36, SAB200050030000) 10 pages

169. A document by Dale P. Hilleary and James M. Lightfoot aboutW48 Disassembly using a Thermal Shock Method, dated April 1989. (Doc # MHSMP-89-12, SAB200050020000) 37 pages

170. A document about Interim Development Report for the TX-53 Assembly and TX-53 Bomb, Engineering Development AEC Atomic Weapon Data-Division 7144, dated April 1962. (Doc # SC-4621(WD), RS 3423/571) 171 pages

171. A document by F. C. Alexander, Jr. regarding Early Thermonuclear Weapons Development: The Origins of the Hydrogen Bomb, Dated May 1969. (Doc # RS 3434/100, SC-WD-68-334, SAC200087100000) 24 pages
    a. A document by the Information Research Division, 3434, regarding History of the Early Thermonuclear Weapons Mks 14,15,16,17,24, and 29, dated June 1967. (Doc # RS 3434/10, SC-M-67-661, SAC200087110000) 59 pages
    b. A document about Final Evaluation Report MK IV MOD O FM Bomb by the Mk IV Evaluation Committee, dated September 13, 1949. (Doc Report # SL.82, SAC200087120000) 113 pages
    c. A Monthly Progress Report of Sandia Laboratory, dated September 18, 1949 through November 1, 1949. (Doc Report # SL-97, SAC200087140000) 88 pages

d. A Historical document Undergoing Classification Review by Frederick Reines about Scientific Director's Report of Atomic Weapon Tests at Eniwetok, Sandstone Handbook of Nuclear Explosions, dated August 1, 1949. (Doc 3 JOL-65-845, SAA200036480000) 100 pages

e. A document of Volume III by B. R. Suydam about Scientific Director's Report of Atomic Weapon Tests at Eniwetok, The Greenhouse Handbook of Nuclear Explosions, Part I- Theory, dated March 17, 1951. (Doc # SAA200036480000) 51 pages

172. A document of Family Committee, Minutes of Meeting, which was held on Friday, March 10, 1950 at 10:00AM in Room A-204, document date is March 10, 1950. (Doc # LAMD-262, SAA200069260000) 4 pages

173. A document of Family Committee, Minutes of Meeting, which was held on Thursday, March 16, 1950 at 1:15 PM in Room A-204, document date is March 16, 1950. (Doc # LAMD-263, SAA200069270000, ADWD-117) 5 pages

174. A document of Family Committee, Minutes of Meeting, which was held on Thursday, March 23, 1950 at 1:15 PM in Room A-204, document date is March 23, 1950. (Doc # LAMD-272, GMX-417, SAA200069280000) 10 pages

175. A document of Family Committee, Minutes of Meeting, which is held on Thursday, March 30, 1950 at 1:15 PM in room A-204, document date is March 30, 1950. (Doc # LAMD-278, GMX-420, SAA200069290000) 7 pages

176. A document of Family Committee, Minutes of Meeting, which was held on Thursday, April 6, 1950 at 1:15 PM in Room B-117, document date is April 6, 1950. (Doc # LAMD-288, GMX-423, SAA20006930000) 11 pages

177. A document of Family Committee, Minutes of Meeting, which was held on Thursday, April 20 1950 at 1:15 PM in Room B-117, document date is April 20, 1950. (Doc # LAMD-289, ADWD-2-124, SAA200069820000) 13 pages

178. A document of Family Committee, Minutes of Meeting, which was held on Thursday, April 27, 1950 at 1:15 PM in Room B-117, document date is April 27, 1950. (Doc # LAMD-306, ADWD-1-129, SAA200069310000) 9 pages

179. A document of Family Committee, Minutes of Meeting, which was held on Thursday, May 4, 1950 at 1:15 PM in Room B-117, document date is May 6, 1950. (Doc # LAMD-308, ADWD-1-133, SAA200069320000) 12 pages

180. A document of Family Committee, Minutes of Meeting, which was held on Thursday, May 11, 1950 at 1:15 PM in Room B-117, document date is May 11, 1950. (Doc # LAMD-309, ADWD-136, SAA200069330000) 13 pages

181. A document of Family Committee, Minutes of Meeting, which was held on Wednesday, May 17, 1950 at 1:15 PM in Room B-117, document date is May 17, 1950. (Doc # LAMD-311, ADWD-139, SAA200069340000) 9 pages

182. A document of Family Committee, Minutes of Meeting, which was held on Thursday, May 25, 1950 at 1:15 PM in Room B-117, document date is May 25, 1950. (Doc # LAMD-319, ADWD-141, SAA2000069350000) 13 pages

183. A document of Family Committee, Minutes of Meeting, which was held on Thursday, June 1, 1950 at 1:15 in Room B-117, document date is June 1, 1950. (Doc # LAMD-323, ADWD-146, SAA200069360000) 18 pages

184. A document of Family Committee, Minutes of Meeting, which was held on Thursday, June 8, 1950 at 1:15 PM in Room B-117, Document date is June 8, 1950. (Doc # LAMD-327, ADWD-148, SAA200069370000) 17 pages

185. A document of Family Committee, Minutes of Meeting, which was held on Thursday, June 22, 1950 at 1:15 PM in Room B-117, document dated is June 22, 1950. (Doc # LAMD-332, ADWD-153, SAA2000069750000) 13 pages

186. A document of Family Committee, Minutes of Meeting, which was held on Thursday, July 6, 1950 at 1:15 PM in Room B-117, document date is July 6, 1950. (Doc # LAMD-344, ADWD-157, SAA200069380000) 7 pages

187. A document of Family Committee, Minutes of Meeting, which was held on Thursday, July 13, 1950 at 1:15 PM in Room B-117, document date is July 13, 1950. (Doc # LAMD-352, ADWD-160, SAA200069390000) 6 pages

188. A document of Family Committee, Minutes of Meeting, which was held on Thursday, July 20, 1950 at 1:15 PM in Room B-117, document date is July 20, 1950. (Doc # LAMD-355, ADWD-163, SAA20006940000) 4 pages

189. A document of Family Committee, Minutes of Meeting, which was held on Thursday, August 3, 1950 at 1:15 PM in Room B-117, document date is August 3, 1950. (Doc # LAMD-375, ADWD-17?, SAA200069830000) 7 pages

190. A document of Family Committee, Minutes of Meeting, which was held on Thursday, August 5, 1950 at 1:15 PM in Room B-117, document date is August 5, 1950. (Doc # LAMD-376, ADWD-174, SAA200069840000) 7 pages

191. A document of Family Committee, Minutes of Meeting, which was held on Thursday August 10, 1950 at 1:15 PM in Room B-117, document date is August 11, 1950. (Doc # LAMD-379, ADWD-176, SAA200069850000) 8 pages

192. A document of Family Committee, Minutes of Meeting, which was held on Saturday, August 26, 1950 at 9:00 AM in Room B-117, document date is August 26, 1950. (Doc # LAMD-399, ADWD-180, SAA200069860000) 6 pages

193. A document of Family Committee, Minutes of Meeting, which was held on Thursday, September 7, 1950 at 1:15 PM in Room B-117, document date is September 7, 1950. (Doc # LAMD-408, ADWD-187, SAA200069870000) 6 pages

194. A document of Family Committee, Minutes of Meeting, which was held on Thursday, September 21, 1950 at 1:15 PM in Room B-117, document date is September 21, 1950. (Doc # LAMD-420, ADWD-194, SAA200069880000) 6 pages

195. A document of Family Committee, Minutes of Meeting, which was held on Thursday, October 5, 1950 at 1:15 PM in Room B-117, document date is October 5, 1950. (Doc # LAMD-445, ADWD-197, SAA200069890000) 14 pages

196. A document of Family Committee, Minutes of Meeting, which was held on Thursday, October 19, 1950 at 1:15 PM in Room B-117, document date is October 19, 1950. (Doc # LAMD-451, ADWD-203, SAA20006990000) 11 pages

197. A document of Family Committee, Minutes of Meeting, which was held on Thursday, October 26, 1950 at 1:15 PM in Room B-117, document date is October 26, 1950. (Doc # LAMD-463, ADWD-206, SAA200069910000) 9 pages

198. A document of Family Committee, Minutes of Meeting, which was held on Wednesday, November 15, 1950 at 1:15 PM in Room B-117, document date is November 15,1950. (Doc # LAMD-470 C.38A, ADWD-217, SAA200069920000) 7 pages

199. A document of Family Committee, Minutes of Meeting, which was held on Thursday, December 7, 1950 at 1:15 PM in Room B-117, document date is December 7, 1950. (Doc # LAMD-494, ADWD-223, SAA200069930000) 10 pages

200. A document of Family Committee, Minutes of Meeting, which was held on Thursday, December 21, 1950 at 1:15 PM in Room B-117, document date is December 21,1950. (Doc # LAMD-508, ADWD-230, SAA200069940000) 7 pages

201. A document of Family Committee, Minutes of Meeting, which was held on Thursday, January 11, 1951 at 1:15 PM in Room B-117, document date is January 11, 1951. (Doc # LAMD-531, ADWD-235, SAA200069950000) 7 pages

202. A document of Family Committee, Minutes of Meeting, which was held on Thursday, January 18, 1951 at 1:15 PM in Room B-110, document date is January 11, 1951. (doc # LAMD-538, ADWD-237, SAA200069960000) 7 pages

203. A document of Family Committee, Minutes of Meeting, which was held on Saturday, February 17, 1951 at 9:00 AM in Room B-117, document date is February 17, 1951. (Doc # LAMD-569, ADWD-242, SAA200069970000) 11 pages

204. A document of Family Committee, Minutes of Meeting, which was held on Thursday, March 1, 1951 at 9:00 AM in Room B-117, document date is March 1, 1951. (Doc # LAMD-584, ADWD-247, SAA200069980000) 4 pages

205. A document of Family Committee, Minutes of Meeting, which was held on Monday, March 19, 1951 at 9:00AM in Room B-117, document date is March 19, 1951. (Doc # LAMD-604, ADWD-3-13, SAA200069990000) 7 pages

206. A document of Family Committee, Minutes of Meeting, which was held on Saturday, March 24, 1951 at 1:15 PM in Room B-117, document date is March 24, 1951. (Doc # LAMD-614, ADWD-252, SAA200070000100) 5 pages

207. A document of Family Committee, Minutes of Meeting, which was held on Wednesday, June 6, 1951 at 9:00 AM in Room B-117, document date is June 6, 1951. (Doc # LAMD-669, ADWD-271, SAA200070010000) 6 pages

208. A Report to the Family Committee on the Feasibility of the Tenex and Flunex Experiments by H. M. Agnew and H. V. Argo, dated May 29, 1950. (Doc # LAMD-321, ADWD-142, SAA200069410000) 10 pages

222. A document of Minutes of the Fifteenth Meeting of the Theoretical Megaton Group by F. C. Hoyt, dated January 25, 1952. (Doc # LAMD-1022, TMG-M15, SAA200069560000) 5 pages

223. A document of Minutes of the Sixteenth Meeting of the Theoretical Megaton Group by Frank C Hoyt, dated February 6, 1952. (Doc 3 LAMD-1042, TMG-M16, SAA200069570000) 5 pages

224. A document of Minutes of the Seventeenth Meeting of the Theoretical Megaton Group by Frank C. Hoyt, dated February 13, 1952. (Doc # TMG-M17, SAA200069580000) 6 pages

225. A document of Minutes of the Eighteenth Meeting of the Theoretical Megaton Group by R. W. Goranson, dated February 20, 1952. (Doc # TMG-M18, SAA200069590000) 7 pages

226. A document of Minutes of the Nineteenth Meeting of the Theoretical Megaton Group by R. W. Goranson, dated February 27, 1952. (Doc # TMG-M19, SAA20006960000) 7 pages

227. A document of Minutes of the Twentieth Meeting of the Theoretical Megaton Group by R. W Goranson, dated March 5, 1952. (Doc # TMG-M20, SAA200069610000) 9 pages

228. A document of Minutes of the Twenty-first Meeting of the Theoretical Megaton Group by R. W. Goranson, dated March 12, 1952. (Doc # TMG-M21, SAA200069620000) 17 pages

229. A document of Minutes of the Twenty-second Meeting of the Theoretical Megaton Group by R. W. Goranson, dated March 19, 1952. (Doc # TMG-M22, SAA200069630000) 10 pages

230. A document of Minutes of the Twenty-third Meeting of the Theoretical Megaton Group by R W. Goranson, dated March 26, 1952. (Doc # TMG-M23, SAA200069640000) 21 pages

THE END

Typical Range of Controlling Parameters for Firing System Design

Characteristic	Minimum	Maximum
Electrical		
Input Voltage	24V	36V
Output Voltage (Operating)	400V	6000V
Output Current	600 Amps	640,000 Amps
Voltage Regulation	± 2%	± 10%
Loads	Single	Multiple
Charge Time	300 ms	5 seconds
Arm Time	1 second	20 years
Output Energy	.5 joule	5790 joules
Reliability	.992	.9995
Normal Environment		
Operating Temperature	-65°F	+170°F
Exposure Temperature	-80°F	+200°F
Shock	100g	18,000g
Vibration	.05 g^2/Hz	2 g^2/Hz
Angular Acceleration	—	289,000 rad/sec^2
Spin Rate	—	16,350 rpm

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Total pages 682, June 6, 1995
Subject: Survey of Weapon Development and Technology (WR708) (U)

WR-708, 1995 edition

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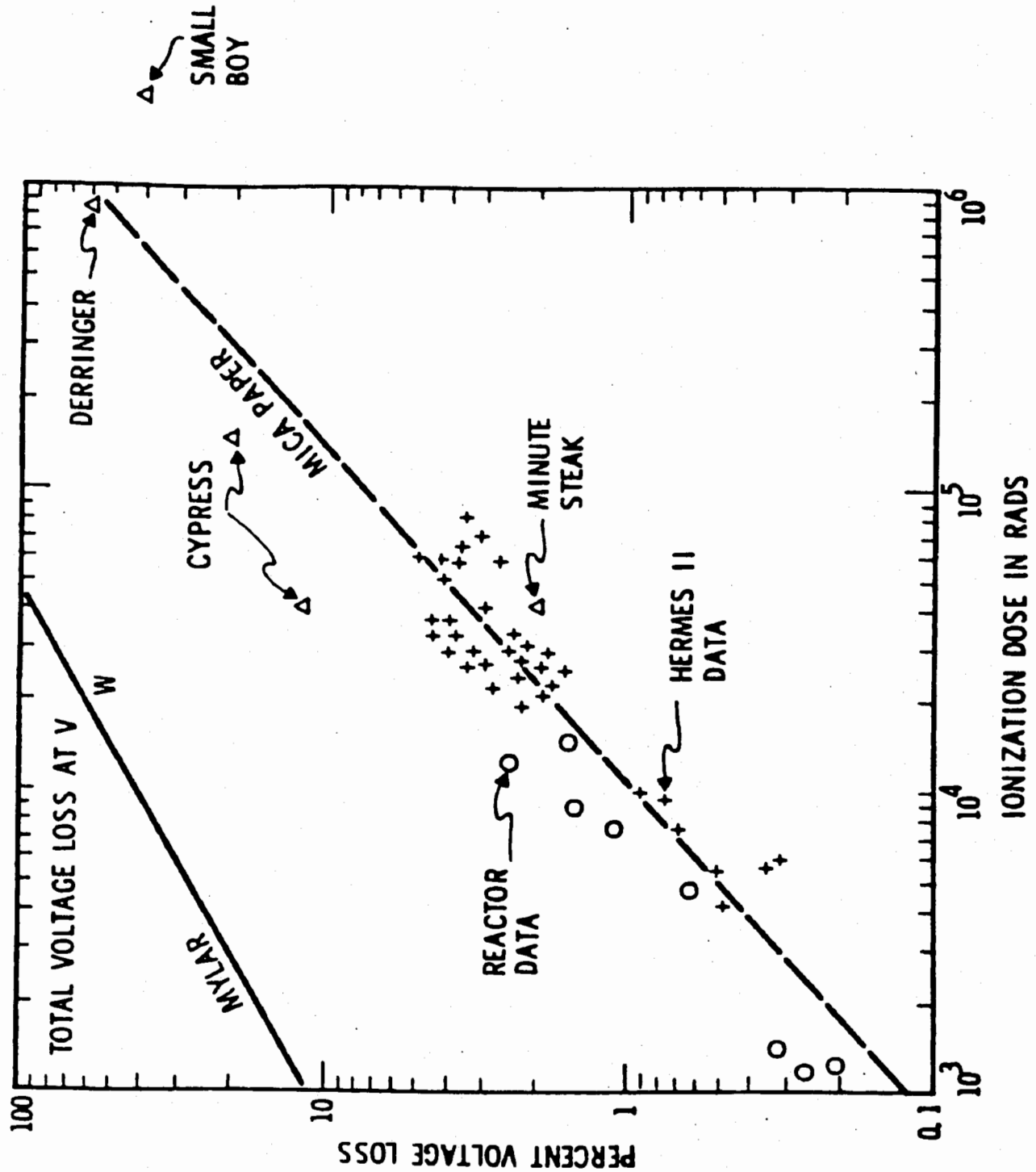
Firing Set Types (U)

CDU — Capacitor Discharge Unit

In its simplest form, the CDU consists of a device for supplying the energy to charge a capacitor upon receipt of arming signals and also a switch of some sort for discharging this energy through the detonators upon receipt of a firing signal.

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SMALL BOY
DERRINGER
CYPRESS
MICA PAPER
MINUTE STEAK
HERMES II DATA
REACTOR DATA
W
MYLAR
TOTAL VOLTAGE LOSS AT V
PERCENT VOLTAGE LOSS
IONIZATION DOSE IN RADS
100
10
1
0.1
10^3
10^4
10^5
10^6

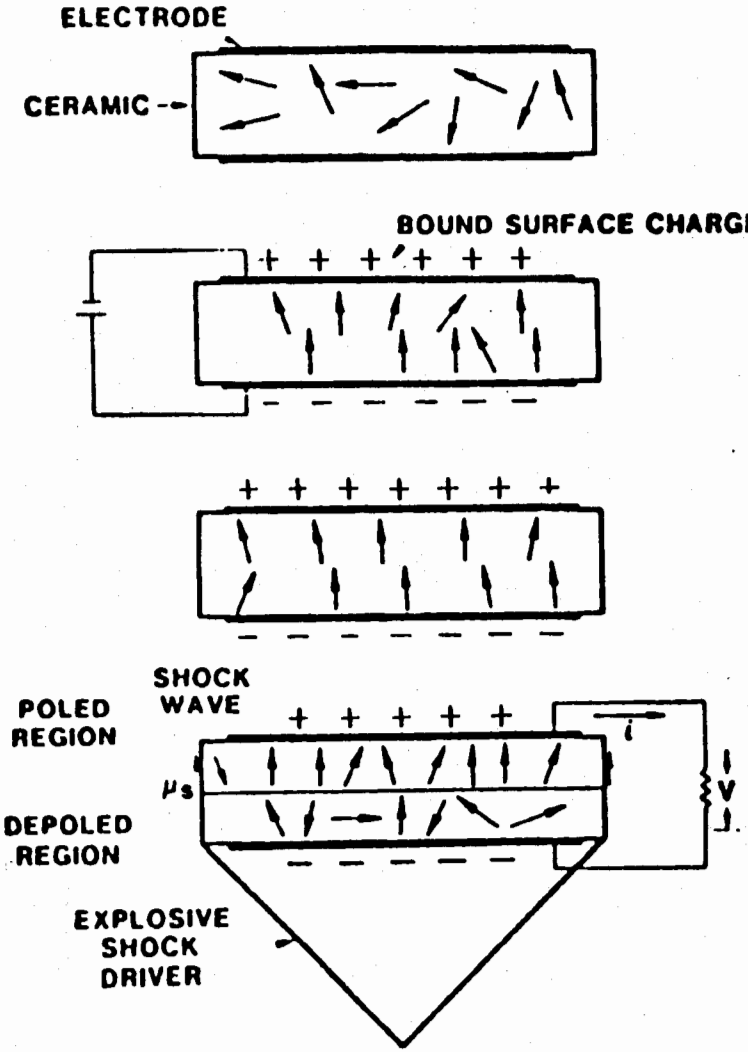
Firing Set Types (U)

FE — Ferroelectric

The FE firing set consists of an explosive plane wave generator and a poled ferroelectric ceramic element. A pressure pulse produced by detonation of the explosive in the plane wave generator causes the release of bound charge from the ceramic element in the detonator load. This technology is also used as the power source in explosive neutron generators.

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THEORY OF OPERATION PRE-ARMED FE



UNPOLED

Polycrystalline Multidomain Ferroelectric Ceramic

POLING PROCESS

Domains aligned (as allowed by crystallographic directions) by impressing external electric field

POLED CERAMIC

Dipoles remain aligned in absence of disturbing independent variable. Bound surface charge remains due to internal electric field

SHOCK DEPOLING PROCESS

Shock wave randomizes dipoles (domains) eliminating internal field, thus freeing bound charge to external circuit.

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Firing Set Types (U)

FM — Ferromagnetic

The FM firing set basically consists of an explosive charge, a ring of ferromagnetic cores and excitation and load windings. Mechanical energy in an explosively driven pressure pulse is transduced into electrical energy in the load winding as the magnetic cores are demagnetized by the shock wave.

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Firing Set Types (U)

CMF — Compressed Magnetic Field

The CMF or "Lobo" firing set converts chemical energy stored in explosive to electro-magnetic energy through magnetic flux compression. A CMF firing system also includes an injector to introduce an initial magnetic flux into the compression volume just prior to the compression event. This injector can be a CDU, FE, FM, or SFE.

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Recent Production Firing Sets

B28	Bomb Stockpile Improvement	CDU
W31	Nike Hercules Stockpile Improvement	CDU
B53	Bomb Stockpile Improvement	CDU
B51	Bombs	CDU
W78	MK4 Reentry Vehicle	SFE
W79	8-inch Projectile	FM
W80	Cruise Missiles	CDU
B83	Bomb	CDU
W84	Ground Launched CM	CDU
W87	MX (Peacekeeper)	CDU
W88	Mk5 Reentry Vehicle	CDU

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Current Production Set

B83 **Redesign** **CDU**

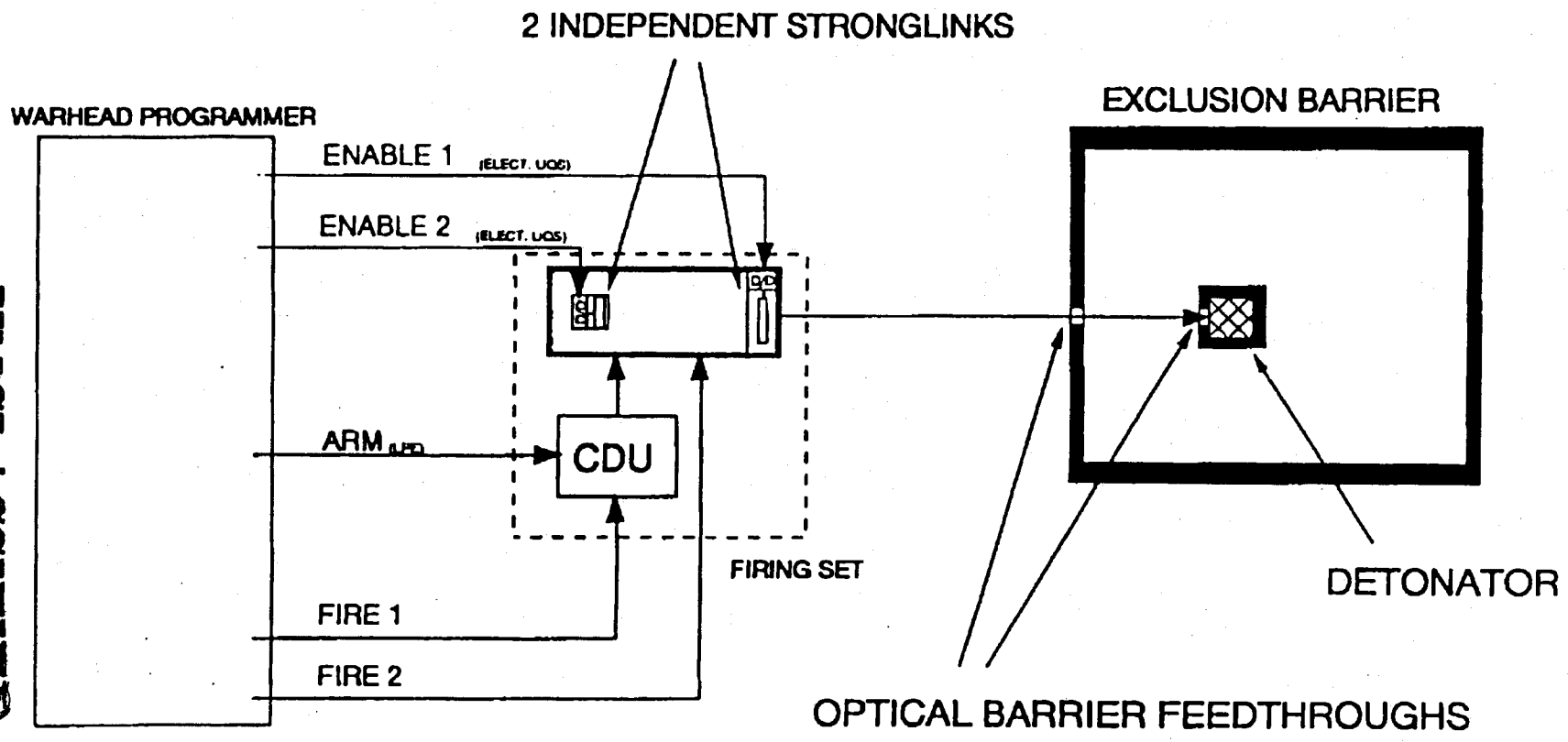
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CONFIDENTIAL
MC2918
BBN-X731-K77
TP1A
TP1B
TP2A
TP2B
TP3A
TP3B
TP4A
TP4B
TP5A
TP5B
TP6A
TP6B
TP7A
TP7B
TP8A
TP8B
TP9
HIGH VOLTAGE
WARNING

OPTICAL FIRING SET

BASELINE SAF ARCHITECTURE



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Neutron Sources

- Internal
- External
  - Technology Involved
  - Evolution of Neutron Generator Development

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NEUTRON MULTIPLICATION RATE

$$\frac{dN}{dt} = \frac{XN}{T}$$

$$\frac{dN}{dt} = \alpha N$$

$$N = N_0 e^{\alpha t}$$

$\alpha < 0$ subcritical

$\alpha = 0$ critical

$\alpha > 0$ supercritical

N = number of neutrons

X = excess number of neutrons per fission

(0.5 - 1.0 assumed to equal 1.0)

T = time per fission generation

(10^{-8} sec)

= multiplication rate

(10^{8} generations/sec)

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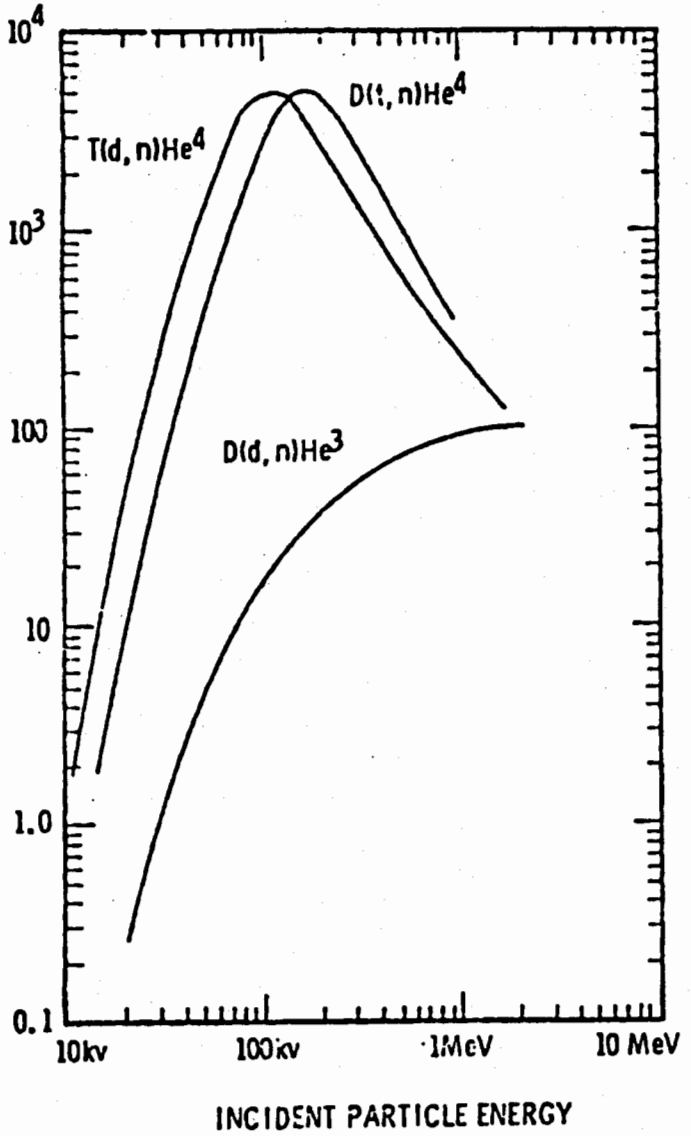


Figure 1. Reaction Cross Section Versus Incident Particle Energy

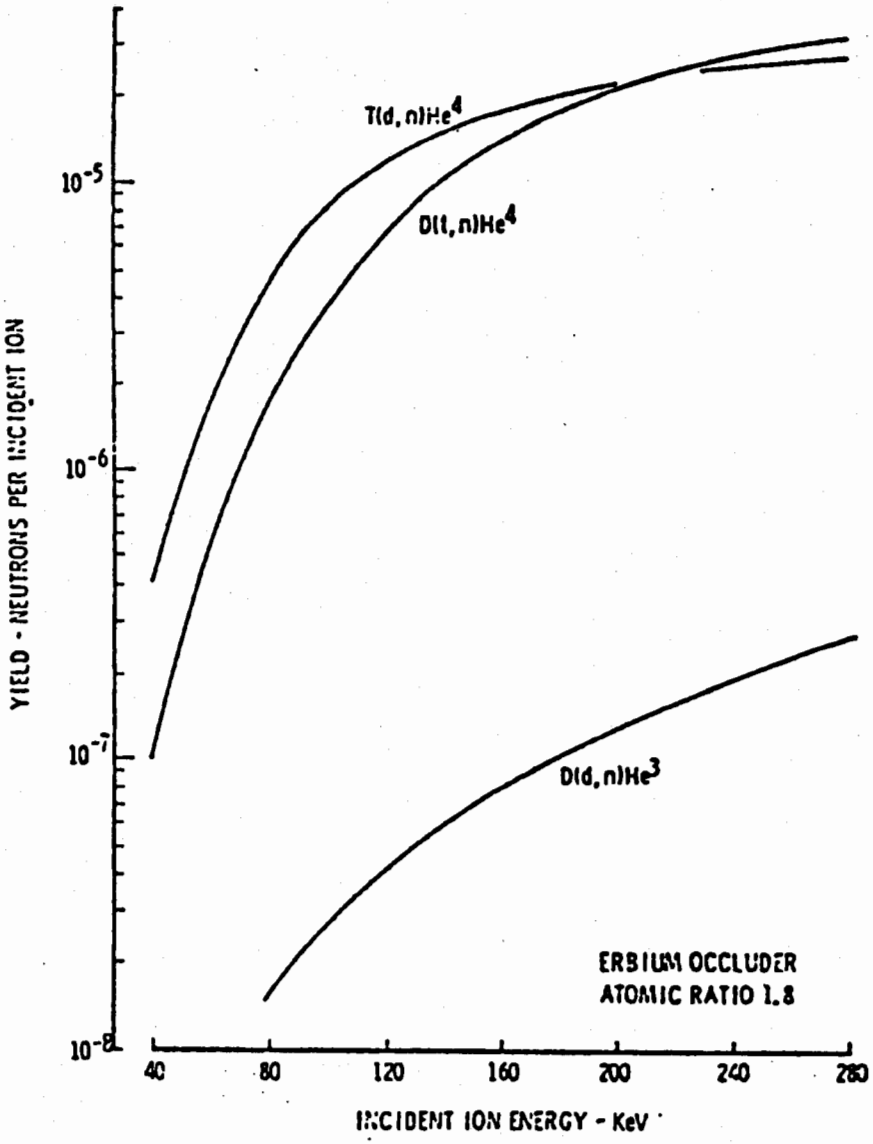


Figure 2. Theoretical Thick Target Yield

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2. R. C. Dougherty, C. E. Spencer, R. W. Gray, "Neutron Generator Study (U)," SAND75-0465, RS 2351/1000, SRD, October 1975.

3. J. C. Crawford, J. H. Renken, "Application of the Acceptance Function Formalism to W74 Initiation Calculations (U)," SAND73-0887, RS 2410/016, SRD, November 1973.

4. W. E. Newman, "W78 Initiation Requirements (U)," SAND75-0607, RS 2351/1008, SRD, January 1976.

5. J. D. Gow, T. S. Church, R. T. DePew, "Zipper Development Chronology 1950- 1960," SC-4533(WD), RS 1411/1267, SRD, December 1960.

6. "A Development History of Neutron Generators (U)," Division 3434, SC-M- 69-79, RS 3434/125, SRD, June 1969.

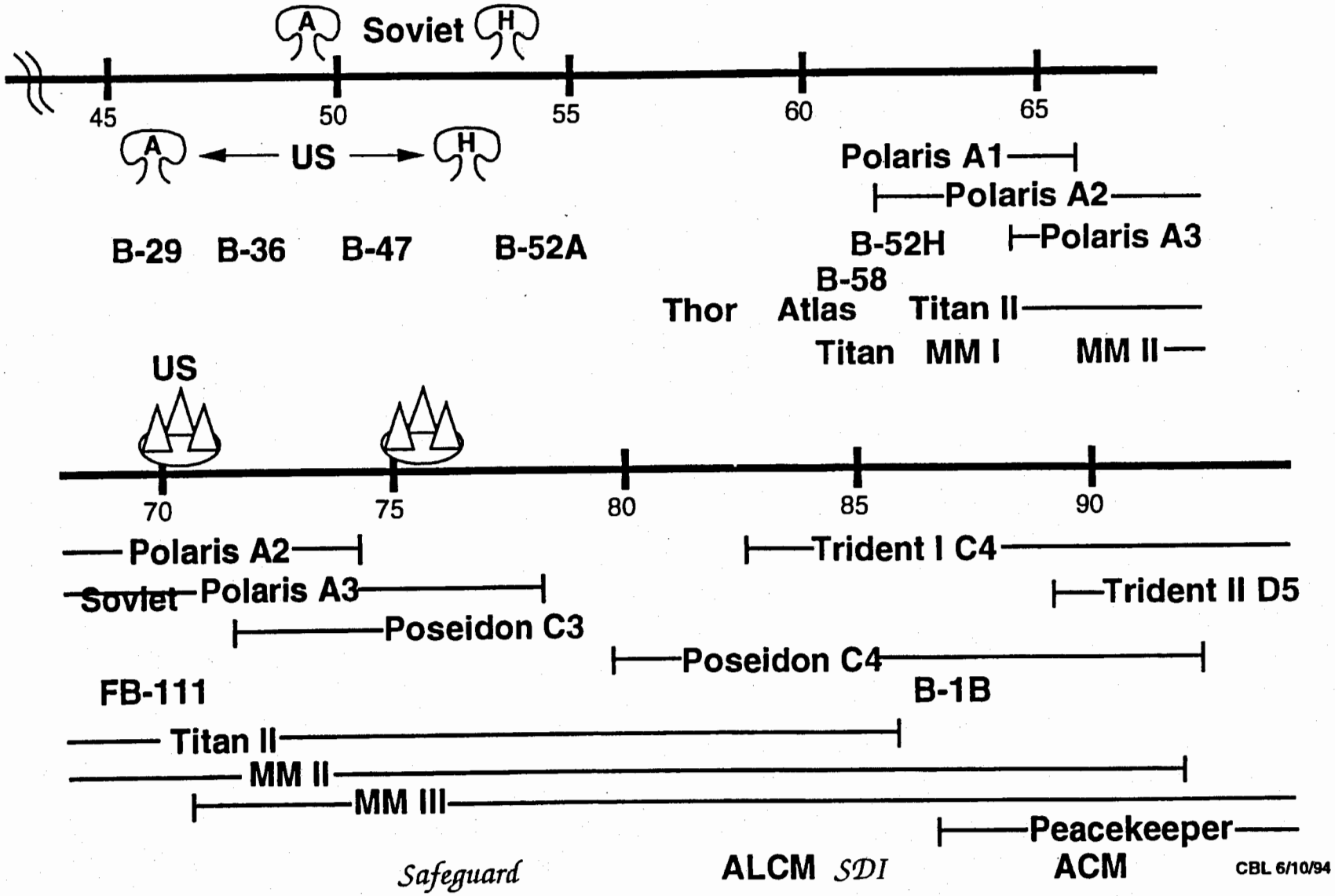
7. J. C. Crawford, "W76 Initiation Requirements (U)," SAND74-0256, RS 2410/056, SRD, November 1974.

8. T. A. Kanneman, "The Physical and Mathematical Model for External Initiation of Nuclear Devices—Interpretation and Application to Systems Analysis and Design (U)," SCTM 146-60(12), RS 3423/219, SRD, January 1963.

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Strategic Delivery Systems



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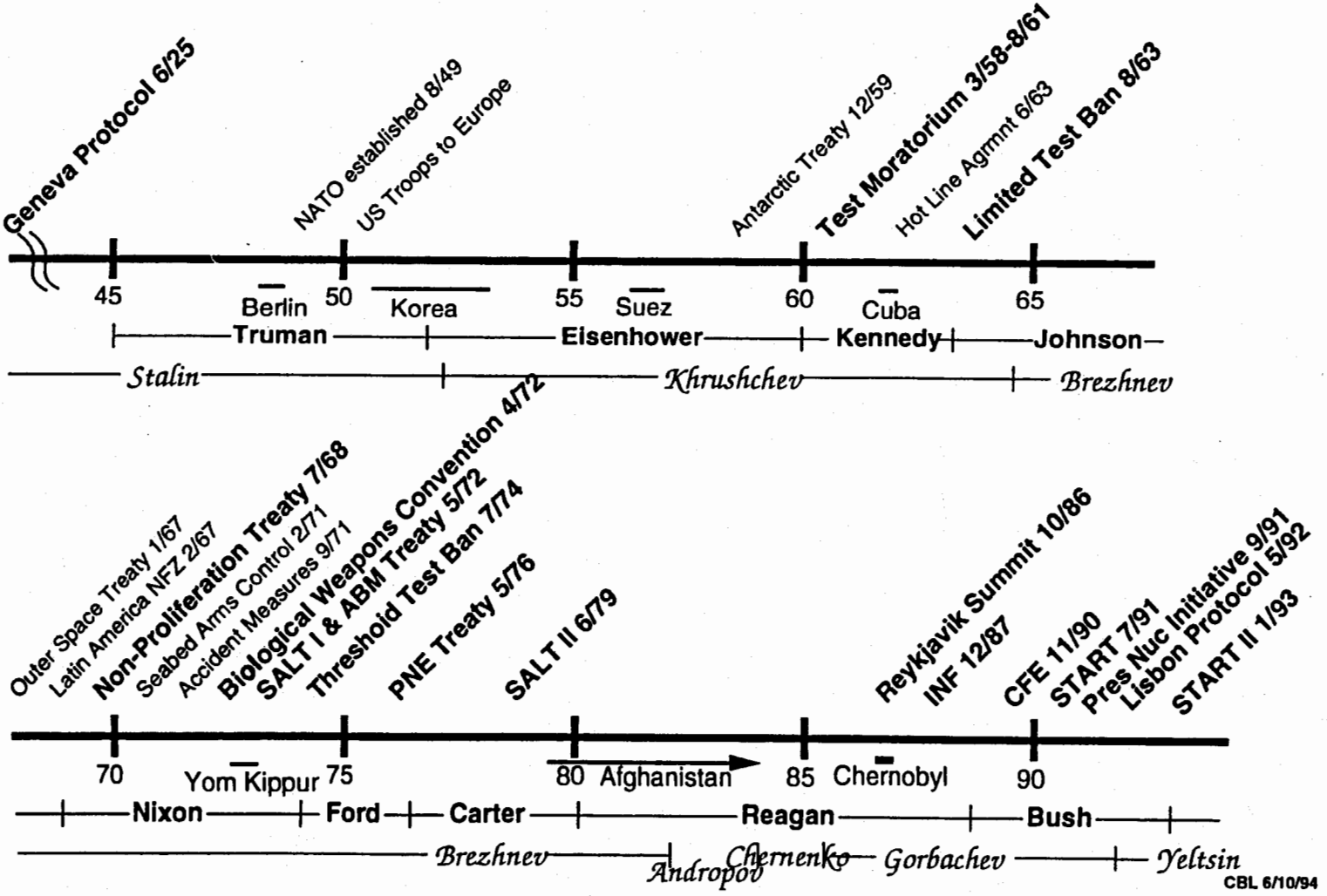
The Evolution of Response Time

1948	Berlin blockade	2 days to assemble
1957	Suez	few hours to launch
1959	DEFCON established	
1960	JSTPS & SIOP	1/3 of bombers ready for immediate take-off
1962	Cuban missile crisis	1/8 on airborne alert

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Arms Control Treaties



CBL 6/10/94

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The Geneva Protocol - 1925

Banned the use in war of asphyxiating, poisonous, or other gases and of bacteriological methods of warfare

US ratified in 1975

All major states now parties

UN Conference on Disarmament is working toward a ban on production and stockpiling

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Test Moratorium - 1958 to 1961

In March 1958, Soviets declared moratorium

In October, negotiations on CTBT began & Eisenhower announced 1-yr U. S. moratorium

May 1960 U-2 incident scrubbed planned summit

Kennedy Administration resumed talks

August 1961, citing French test, Soviets resumed testing

Soviets conducted over 50 tests in the last 3 months of 1961

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The Limited Test Ban Treaty - 1963

Limited nuclear tests to underground

Original signatories were US, Soviet Union, and UK

US ratified 10/63

More than 100 parties now

France ceased above ground tests in 1974,
China in 1980

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The Nonproliferation Treaty - 1968

Eisenhower proposed "Atoms for Peace" in 1953

IAEA established in 1957 to promote and monitor

Nuclear Nonproliferation Treaty was negotiated from 1965 and signed in 1968

NPT Review Conferences every 5 years

After 25 years (1995) a majority vote will determine indefinite or another fixed extension

In exchange for peaceful use of atomic energy, signatories agree to safeguards

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Biological and Toxin Weapons Convention

Outlaws development, production, stockpiling of all biological or toxin weapons and requires destruction of existing stocks

No specific verification provisions

Signed in 1972 and ratified by the US in 1975

Nixon ended US program in 1969 and destroyed stocks

Soviet incident at Sverdlovsk in 1979

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SALT I - 1972

Interim Agreement on Strategic Offensive Arms

Limited launchers (silos and sub tubes) to the then current number

US - 1710 SU - 2347

Limit on heavy launchers (SS-9 and later SS-18)

Five year duration

US ratified in Oct 1972

Reagan repudiated SALT I and II in May 1986

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ABM Treaty - 1972

Johnson and McNamara tried to convince Kosygin at Glassboro to limit ABM systems - June 1967

US announced Sentinel program in September1967

ABM talks were postponed by Soviet invasion of Czechoslovakia in 1968

Nixon changed concept to Safeguard, protecting ICBMs and Washington, DC

Treaty prevents defense of territory, limits to 2 sites with 100 interceptors, limits LPARS

Forbids mobile ABMS or sea, air, or space systems

OPP, Krasnoyarsk, SCC, capabilities questions

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Threshold Test Ban Treaty - 1974

Signatories are the US, Soviet Union, and UK

Limits nuclear tests to 150kT

Verification by NTM (seismic)

A two page treaty

Joint Verification Experiment in 1988

US ratified in 1989

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Peaceful Nuclear Explosives Treaty - 1976

Limited peaceful nuclear explosives to 150kT

Permitted maximum aggregate yield of 1.5 MT, with on site monitoring for yields above 150kT

Plugged a loophole in the TTBT

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START Treaty - 1991

Signed July 31, 1991, 5 months before the end of SU

Lisbon Protocol, signed May 1992, committed Russia, Ukraine, Belarus, and Kazakhstan to START (and NPT)

START limits SNDVs and deployed warheads:

	START	US forces*	Soviet forces*
SNDVs	1600	2246	2500
ICBM & SLBM Warheads	4900	8210	9416
Total Warheads	6000	10563	10271
Heavy ICBM Warheads	1540	------	3080
Mobile ICBM Warheads	1100	------	618
Throw-wt ICs & SLs (metric tons)	3600	2631	6626

*as of 9/90

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The President's Nuclear Initiative-1991

Sept 1991

- Eliminate ground launched tactical nuclear weapons
  - Lance and AFAPs
- Withdraw tactical nuclear weapons from surface ships, subs and P-3 bases
  - B-57, SLCM, B-61
- Stand down strategic bombers from alert
- Stand down MMII
- Cancel mobility for PK and SICBM
- Cancel SRAM II
- Propose joint elimination of MIRVed ICBMs

Jan 1992

- Build only 20 B-2s
- Cancel SICBM
- Halt production of ACM
- Halt production of W88 for Trident II

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START II - 1993

Treaty between the Russian Federation and US, signed by Bush and Yeltsin January 3, 1993, codifed agreements of the Washington summit of June 17, 1992.

START II builds on START - and requires START

	START	START II Ph1	START II Ph2
Start Warheads	6000	3800-4250	3000-3500
ICBM & SLBM Warheads	4900	no sublimit	no sublimit
MIRVed ICBM Warheads	N/A	1200	0
SLBM Warheads	N/A	2160	1700-1750
Heavy ICBM Warheads	1540	650	0
Mobile ICBM Warheads	1100	1100	1100

Phase one to be complete 7 years after entry-into-force, Phase two by 2003

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Books of interest

The Making of the Atomic Bomb, Richard Rhodes, 1986.
Pulitzer prize winner, follows the scientific discoveries that led to the bomb, particularly good at the personalities involved, finishes with vivid descriptions of Hiroshima and Nagasaki. Excellent and entertaining.

At the Highest Levels, Michael R. Beschloss and StrobeTalbott, 1993.
Intimate details of the end of the Cold War, as seen at the top.

Lenin's Tomb, David Remnick, 1993.
Details the end of the Soviet Union from the viewpoint of the Russian people and their legacy. Choppy, but a very human picture of the great event.

The Wizards of Armageddon, Fred Kaplan, 1983.
Follows the policy and strategy decision regarding nuclear weapons, much emphasis on the early RAND personalities. Very good and readable.

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Nonproliferation Initiative

What Constitutes a Weapon of Mass Destruction

- Indiscriminate nature of use
- Effect not confined to Belligerents
- Excessive injury -- "cruel and unusual"
- Inability to defend against effectively
- Use would overwhelm medical and evacuation resources
- Notion of "terror"

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ARMS CONTROL IN THE ANCIENT WORLD

1269 BC	Earliest known peace treaty (Egypt and the Hittites), cemented by the marriage of Ramses II to a Hittite princess.
1100 BC	Philistines restrict the use of iron by the Israelites (1 Samuel 13:19-20).
700-800 BC	"...and they shall beat their swords into plowshares..neither shall they make war anymore" (Isaiah 2:2-4).
546 BC	Following the first recorded arms control conference, a "cessation of armaments" ends 72 years of hostilities in the Yangtse River Valley in Honan Province, China.

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ARMS CONTROL IN THE ANCIENT WORLD (CONT'D)

400-500 BC	Athens and Sparta agree to dismantle fortifications although during the negotiations the Athenians hedged their bet by continuing to build their ramparts "high enough to be defended" (Peloponnesian War, Thucydides). Note that, according to the Aristophanes, the women of Athens and Sparta, under the leadership of Lysistrata, tried a different approach to forcing an end to hostilities!
450 BC	Socrates to Glaucon -- no use of poisoned weapons or poisoned water (The Republic, Plato).
300-400 BC	No weapons concealed in wood, no barbed or poisoned points, no points "blazing with fire" (India's Book of Man).
202 BC	After the battle of Zama, Carthage is required to surrender all war elephants and all but 10 triremes to Rome (Book XXX, Livy).

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Nonproliferation Initiative

The Changing Context

Old	New
Bipolar Rigidity	Multipolar Complexity
Predictable	Uncertain
Communism	Nationalism/Religious Extremists
U.S. Dominant Western Power	U.S. Militarily No.1 - Not Economical
Fixed Alliances	Ad Hoc Coalitions
"Good Guys and Bad Guys"	"Grey Guys"
U.N. Paralyzed	U.N. Viable

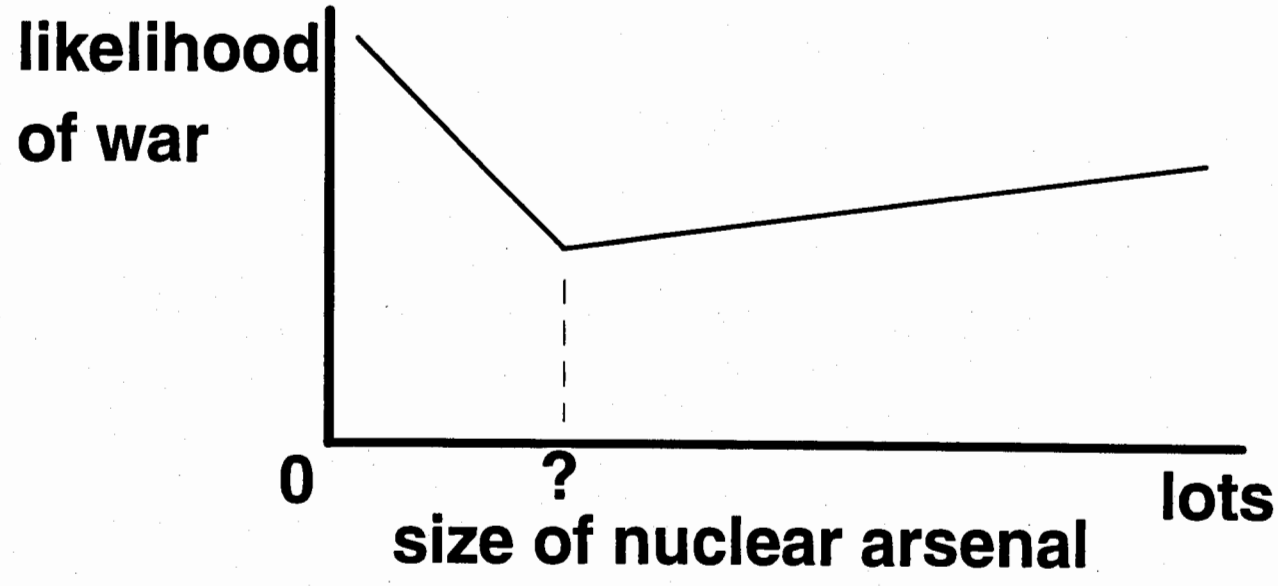
Ref.: National Security in the 1990s: Defining a New Basis for U.S. Military Forces, Rep. Les Aspin, Chrmn House Armed Services Committee, January 6, 1992

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Why Not Zero?

Many nations and individuals want us to completely eliminate weapons -- attractive philosophy but dubious policy:



There may be things worse than nuclear weapons (e.g. biologics)

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There have been some Nonproliferation Successes

-- Sweden abandoned its programs in the 1970s.

-- South Africa stopped its programs in 1992 (6 weapons).

-- Argentina and Brazil renounced their programs.

-- Taiwan and South Korea abandoned their programs in the 1980s.

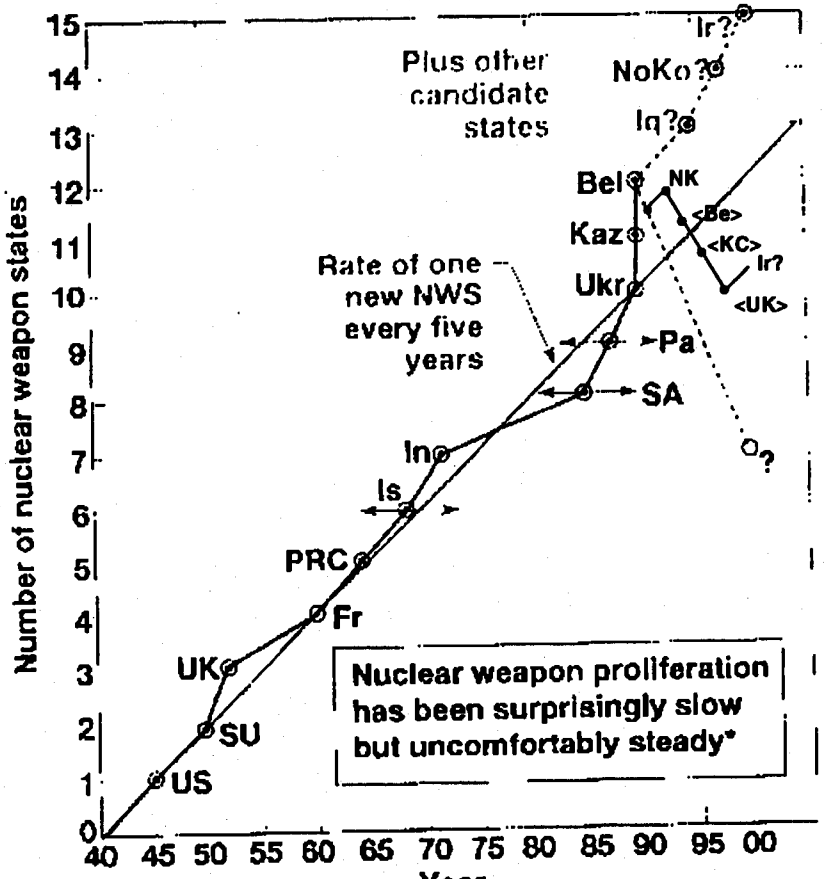
-- Iraq's program "put on hold" by Desert Storm and UN Resolution 687 and 715.

-- Belarus, Kazakhstan, and Ukraine (?) have agreed to return the FSU weapons to Russia.

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How many nuclear weapons states will there be in the year 2000?



*Data from news and journal articles in 1992

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Nonproliferation Initiative

Nuclear Proliferation: A Current Status

- Acknowledged/Declared Nuclear Weapon States
  -- US, UK, China, France, Russia
- Undeclared but widely suspected Nuclear Weapon States
  -- India, Pakistan, Israel
- "Inheritors" of Soviet weapons
  --Ukraine, Kazakhstan, Belarus
- Virtual Nuclear Weapon States (e.g., weapon capabilities but no weapons)
  --Japan, Germany
- Threshold Nuclear Weapon States
  --North Korea
- Aspiring Proliferators
  --Iraq, Iran, Libya, Algeria, various terrorist organizations
- Rollback cases
  --Argentina, Brazil, Sweden, Taiwan, South Africa

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Nonproliferation Initiative

Goals of Proliferation Controls (non → counter)

-- **REMOVE MOTIVATION** FOR POSSESSION OF NUCLEAR WEAPONS

-- **INTERDICT DEVELOPMENT AND ACQUISITION**

-- **DETER EMPLOYMENT** OF KNOWN OR SUSPECTED STOCKPILES OF NUCLEAR WEAPONS

-- **ELIMINATE INFRASTRUCTURE** BY PERSUASION, INTERNATIONAL SANCTIONS (E.G., Res 687)

-- PROACTIVELY **DESTROY FACILITIES** (E.G., Osirak)

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Incorporation of Nonproliferation into US National Security Policy

A successful nonproliferation strategy must address the underlying security concerns that drive the quest to obtain advanced weapons and must encompass contingency planning to deal with these weapons should prevention fail.

National Security Strategy of the United States
August 1991

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Secondary Impacts of Nonproliferation Initiatives

o NPT//NPT Extension Conference (1995):
  -- New and more intrusive inspections regimes
  -- An increased call for transparency
  -- More downward pressure on the stockpile from the "have nots"
  -- Continued pressure against nuclear testing

o Negotiations on controls on fissile materials:
  -- Codify in-place current US and Russian practices
  -- Inspection regimes and transparency
  -- Possible attempts to restrict tritium production

o Export Controls
  -- Heightened concern over "dual use" systems and commodities

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Nonproliferation Initiative

Options across the Nonproliferation -- Counterproliferation Spectrum

disincentives ⟷ **incentives**

venues

Economics — blockades, sanctions — export controls — foreign aid

Politics — political isolation — int'l organizations — alliances

Military Force — war — peacekeeping — military sales — military asst. — covert operations

confrontation ⟷ **cooperation**

COUNTERPROLIFERATION ⟷ **NONPROLIFERATION**

Issues on the Nonproliferation Platter

- Control over the nuclear arsenal of the FSU.
- North Korea
- The 1995 NPT Extension Conference
- China
- The Israeli nuclear arsenal
- The nuclear relationship between India and Pakistan
- Iran

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

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SESSION XVIII

FIELD TRIP TO THE INTER-SERVICE NUCLEAR WEAPONS SCHOOLS' WEAPON DISPLAY AREA

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February 16, 1998

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NAME: Patty Ulve
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~~TCG-DP-1, 04/86~~
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~~TCG-UC-2, 10/93~~

~~CRITICAL NUCLEAR WEAPON DESIGN INFORMATION~~
~~– DOD DIRECTIVE 5210.2 APPLIES –~~

~~NUCLEAR WEAPON DATA~~

~~SIGMA 1 & 2~~

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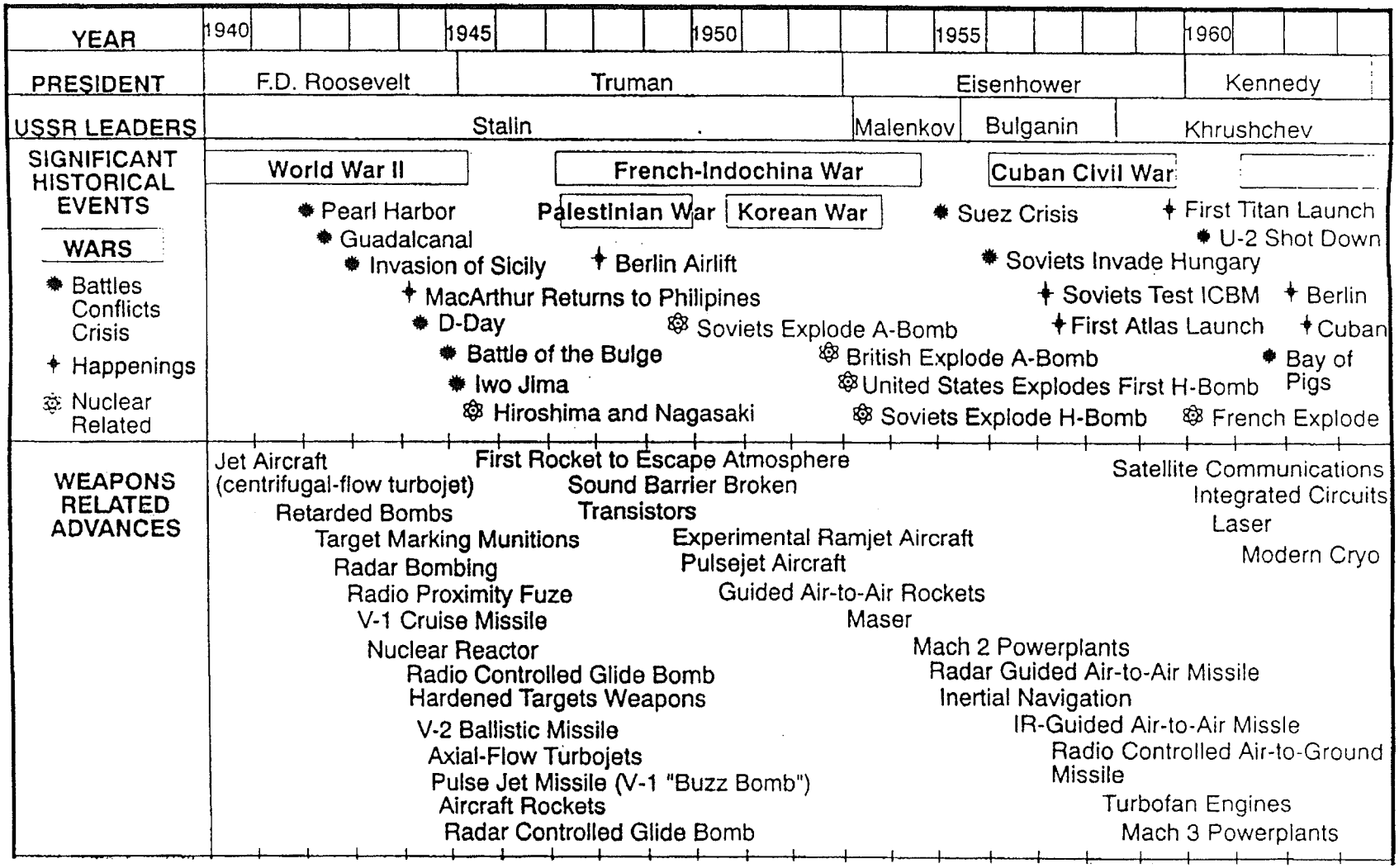
National Security Strategy: Deterrence

Decade	Implementation
1950	Massive Retaliation
1960	Flexible Response
1970	Flexible Response
1980	Flexible Response
1990	Last Resort

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SIGNIFICANT HISTORICAL EVENTS RELATIVE TO NUCLEAR WEAPONS

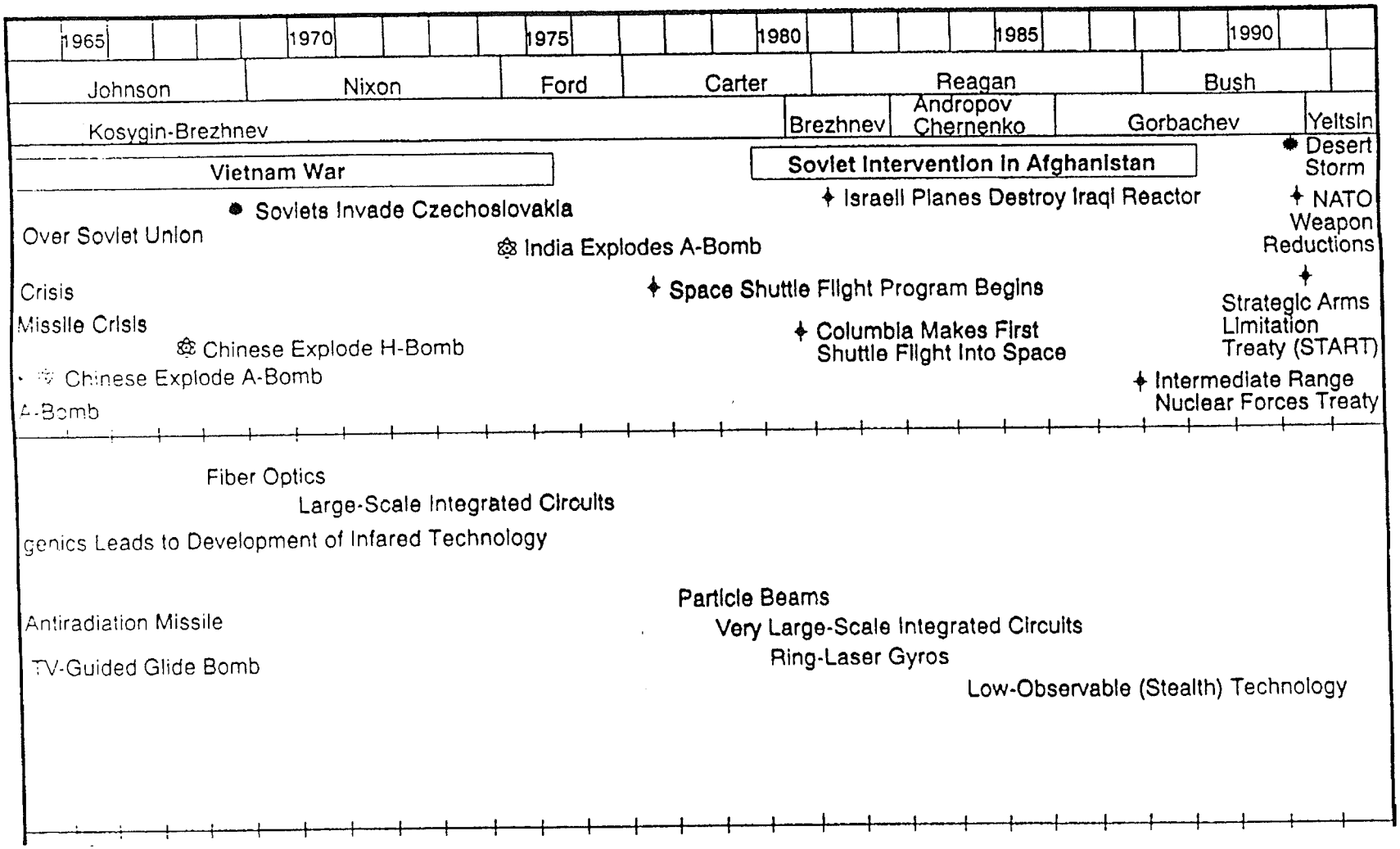


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SIGNIFICANT HISTORICAL EVENTS RELATIVE TO NUCLEAR WEAPONS



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Strategy, Arms Control, and Weapon Systems Technology Drive Stockpile Requirements

Strategy	Threat	Tech.	Size/Wt.	Yield	Arms Control	Number
1950 Massive retaliation	Global	A/C & missiles inaccurate	Large	Very high	Very limited talks	Growing
1960 Flexible response	Global Theater	A/C & missiles improve	Decrease	Decrease	Limited talks	Growing
1970 Flexible response	Global Theater	A/C & missiles improve accuracy	Decrease even more	Tactical needed lower yields	SALT ABM limitations	Decline
1980 Flexible response	Global Theater	A/C & missiles very accurate	Large decrease	Continued decrease	Mutual elimination & reduce	Decline more
1990 Last resort	Theater Global	A/C & missiles very accurate	Remain small	Remain same	Large cuts mutual elimination/ unilateral	Large reduction

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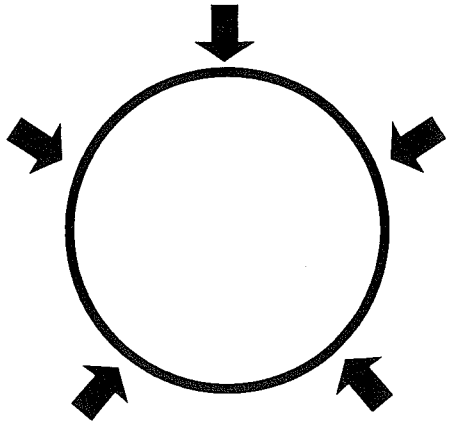
SELECTED HARDWARE ORIENTATION

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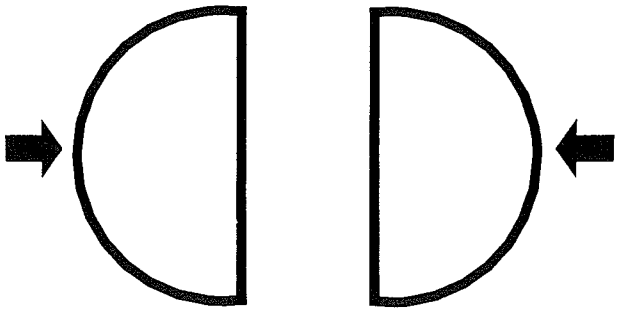
Fission Primaries

IMPLOSION



Critical Mass Achieved with Compression from HE

GUN TYPE



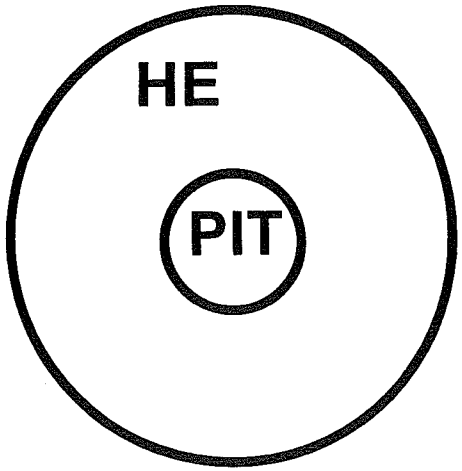
Critical Mass Achieved with "Lots of Special Nuclear Material"

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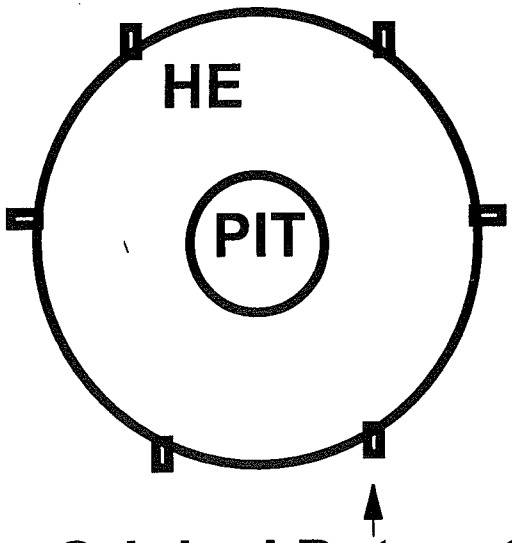
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Fission Primary

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Detonators Required to Fire the HE

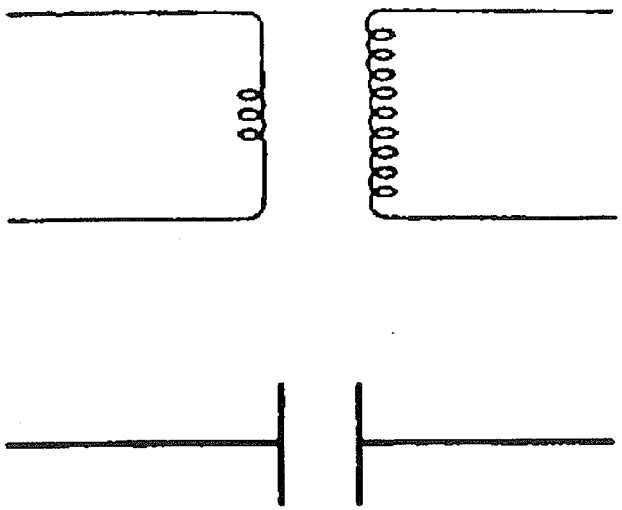


Original Detonators Large

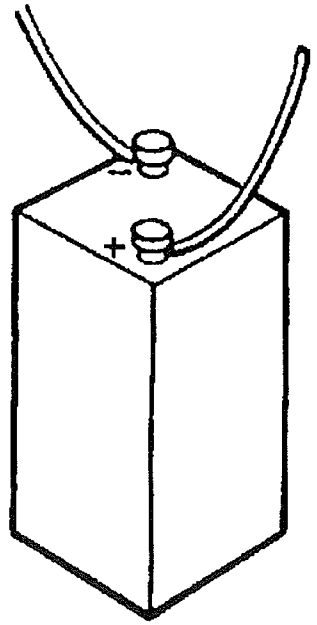
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Basic Electronics Needed to Fire the Detonations



FIRE SET
Evolved from Large to Compact

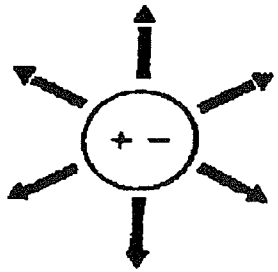


POWER SOURCES
Originally Lead Acid (car battery style)
Evolved to Thermal Batteries

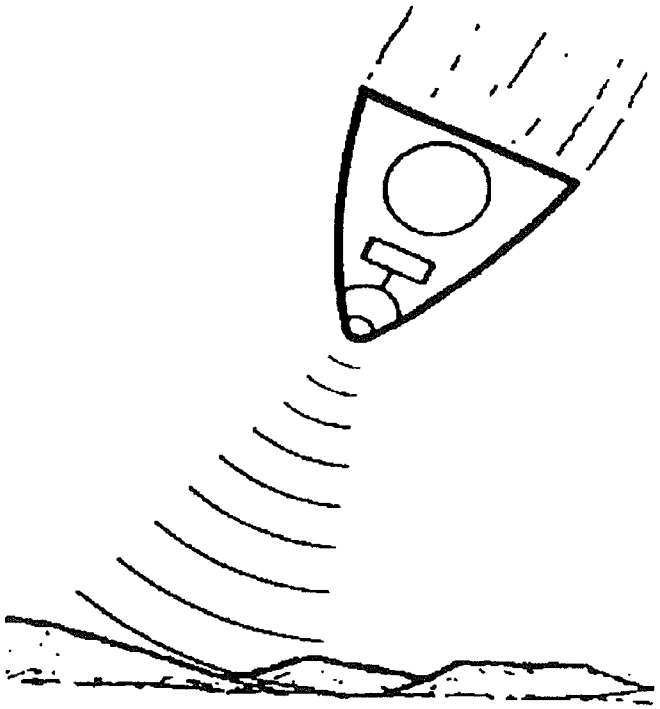
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Additional Elements Required for Detonation

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Neutron Source



Fuzes

- Height of Burst
- Impact

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Basic Elements of a Nuclear Weapon

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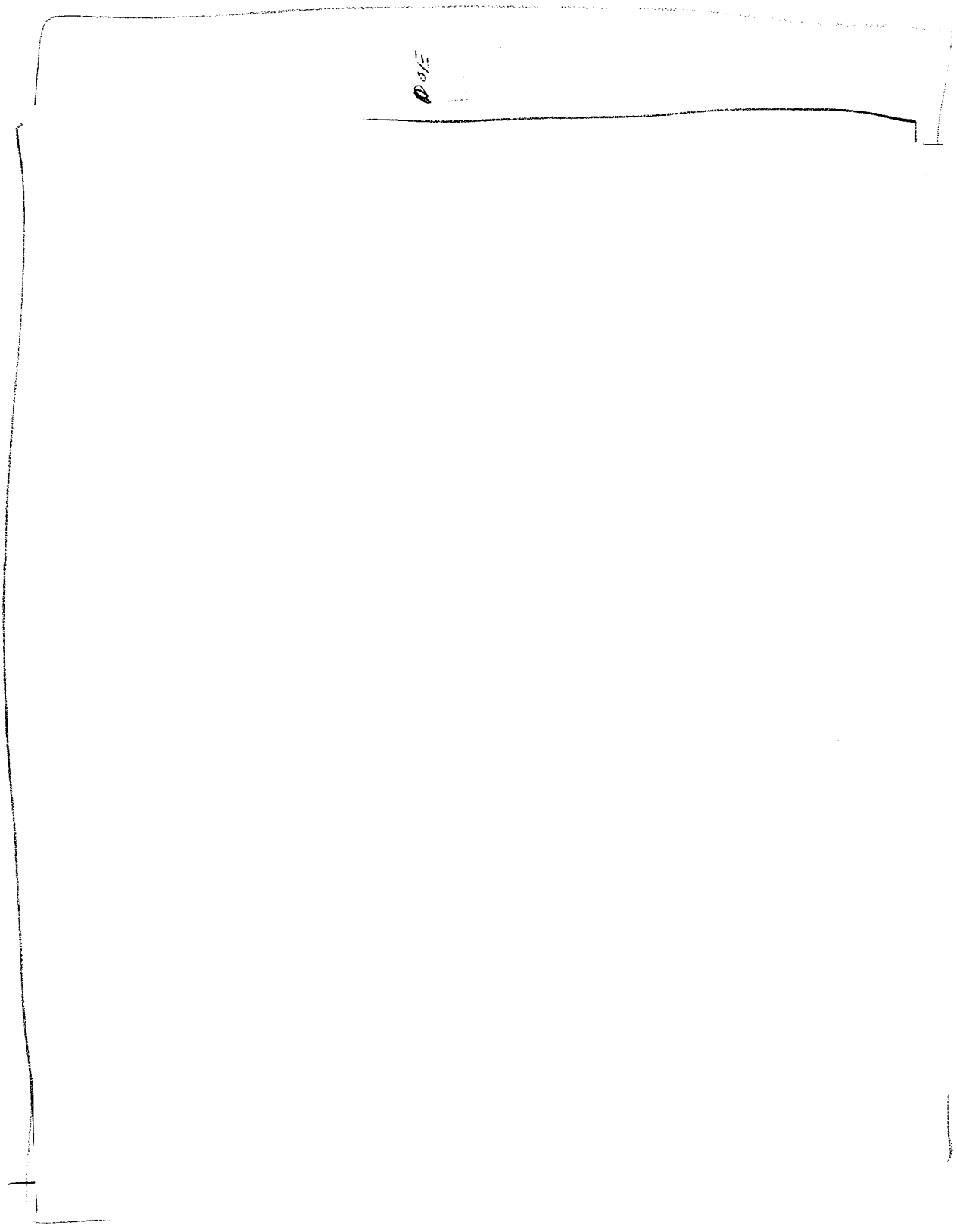
GAS BOOSTING

- INITIAL FISSION RAISES BOOST GAS TO FUSION TEMPERATURES

- D • T REACTIONS RELEASE A FLOOD OF HIGH ENERGY NEUTRONS FOR FISSIONING OF Oy AND/OR Pu

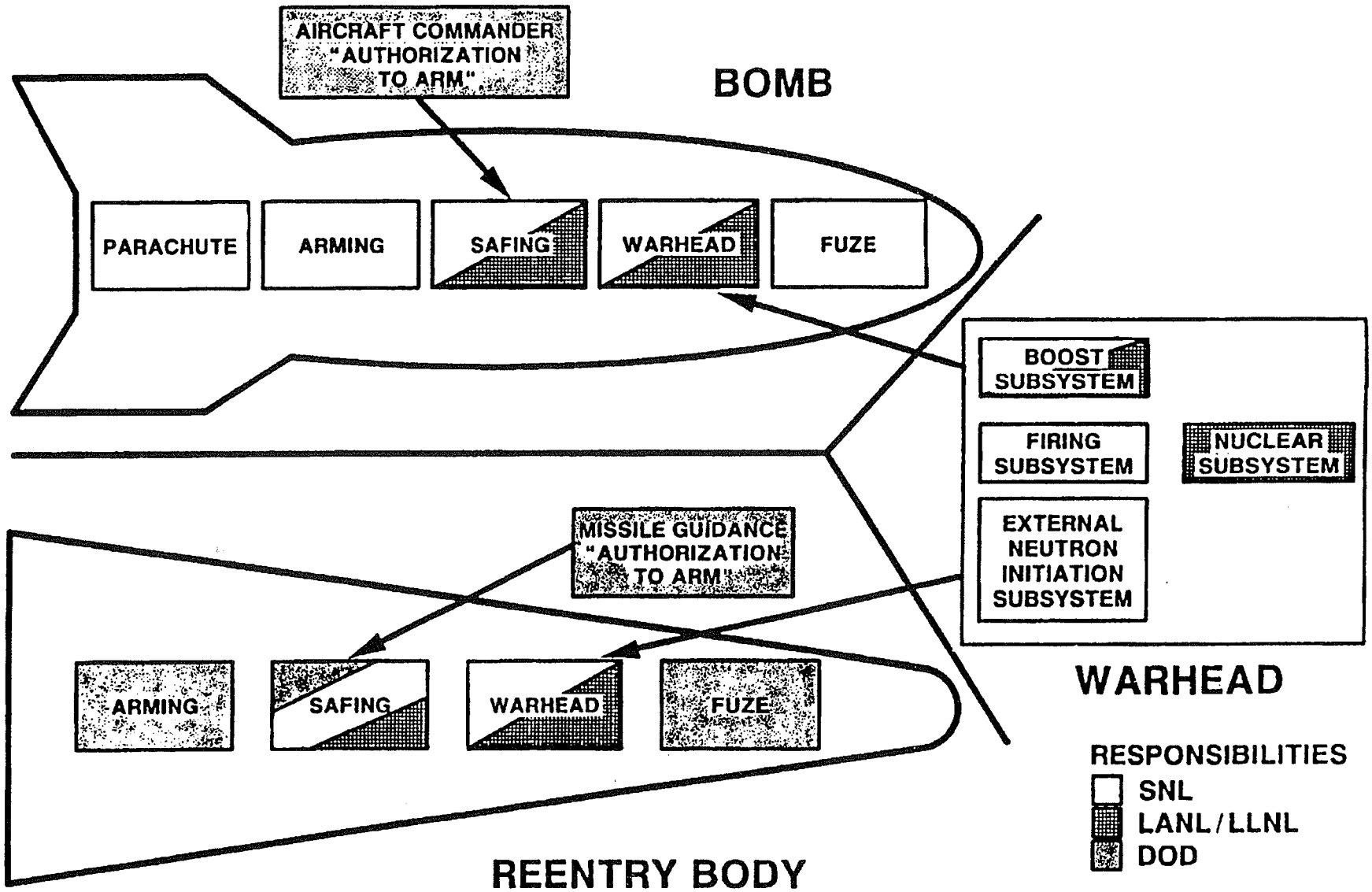
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DIVISION OF RESPONSIBILITIES



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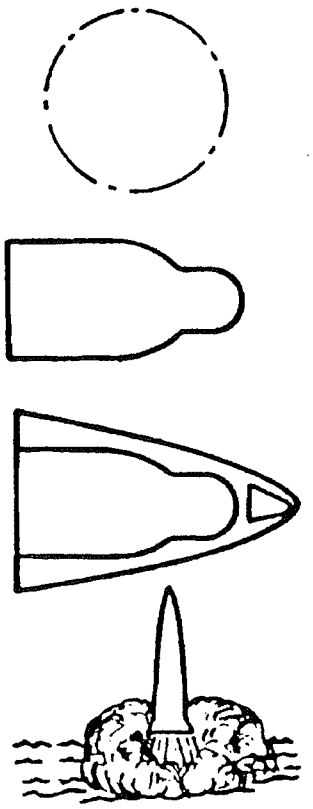
TERMINOLOGY

NUCLEAR PACKAGE
PHYSICS PACKAGE
⇨ PRIMARY/SECONDARY
(Includes High Explosive)

NUCLEAR WARHEAD
⇨ NUCLEAR PACKAGE &
WEAPON ELECTRICAL
SYSTEM & PLUMBING

NUCLEAR WEAPON
⇨ NUCLEAR WARHEAD &
ARMING & FUZING &
AERODYNAMIC CASE,
ALSO REENTRY VEHICLE

NUCLEAR WEAPON SYSTEM
⇨ NUCLEAR WEAPON & DoD
DELIVERY SYSTEM



- THE TERM <u>NUCLEAR DEVICE</u> USUALLY IMPLIES A TEST WARHEAD BUT IS SOMETIMES USED IN A PLACE OF EITHER NUCLEAR PACKAGE OR WARHEAD

- THE ARMY USED THE TERM NUCLEAR WARHEAD SECTION TO INCLUDE WARHEAD + AK + BALLISTIC BASE

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WEAPON PROGRAM OBLIGATIONS

STOCKPILE MANAGEMENT:

MAINTENANCE OF THE NATIONAL STOCKPILE OF NUCLEAR WEAPONS IN A SAFE, SECURE, RELIABLE, READY CONDITION

WEAPONIZATION:

DEVELOP AND PRODUCE NUCLEAR WEAPONS FOR STOCKPILE AS JOINTLY AGREED TO BY DOD & DOE AND AS AUTHORIZED BY THE PRESIDENT

WEAPON TECHNOLOGY:

PURSUE TECHNOLOGY IN THE SCIENCE & ENGINEERING OF NUCLEAR WEAPONS SO THAT OUR UNDERSTANDING & ABILITY TO DEVELOP IS SECOND TO NONE

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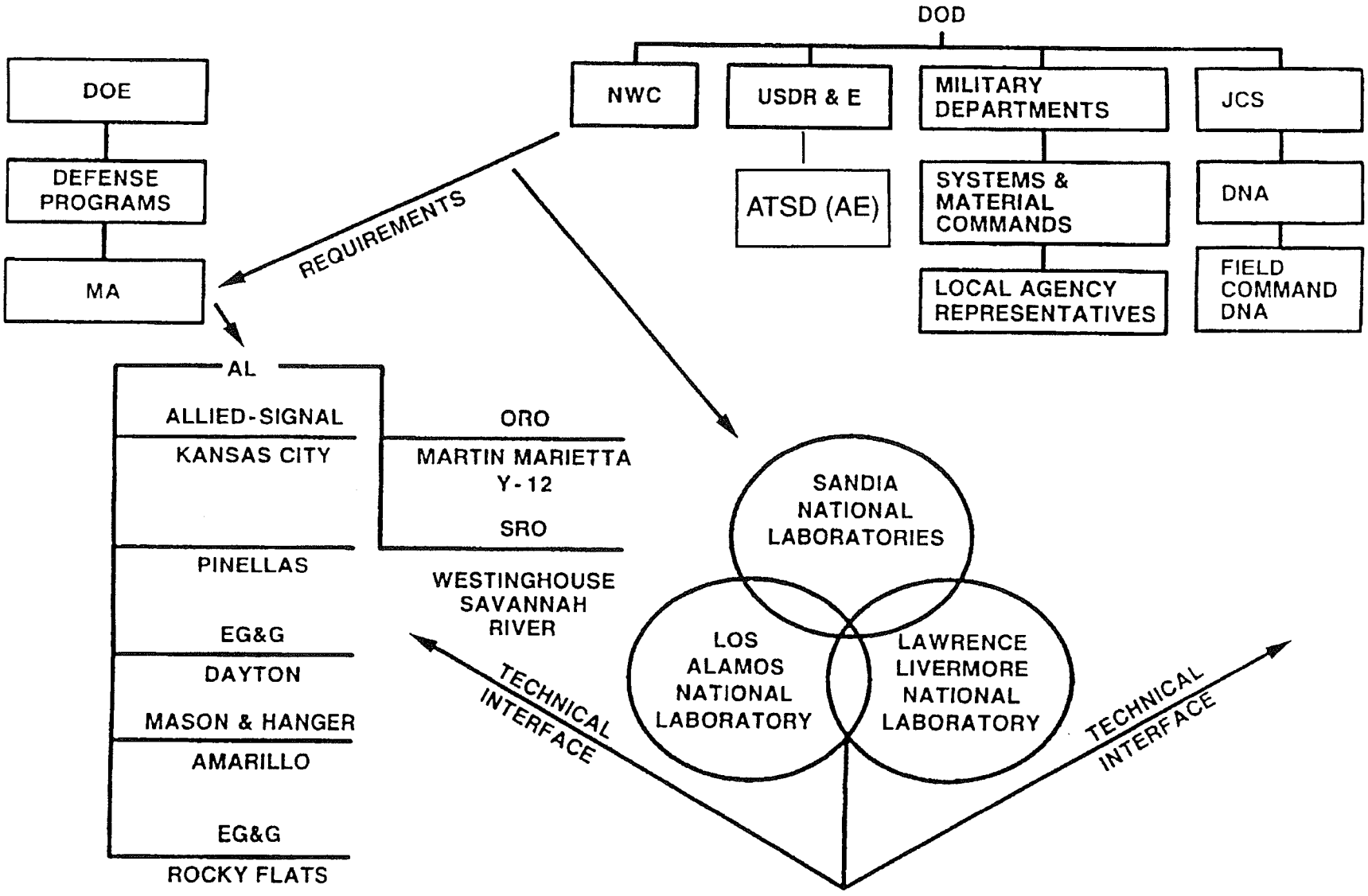
As the nuclear weapons systems integrator for the DOE, Sandia has responsibility for:

- Fire set development--neutron generator, batteries, capacitors, etc.
- Electrical & mechanical interface compatibility
- Electrical detonation safety
- Use control & use control equipment
- Handling and aneillary equipment
- Stockpile surveillance (reliability)--testing & evaluation
- Military training & manuals
- Field support
- Weapon systems (including DoD hardware) independent evaluations
- DOE & DoD security facility upgrade
- Safe secure trailers (total life cycle) & DOE courier training
- Neutron generator production

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SANDIA-DOE/DOD INTERFACES
WEAPON PROGRAM



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Rocky Flats
Golden, Colorado
-Historical Context-

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Contractor:	**EG&G**
Principal Missions:	**Fabrication of beryllium, plutonium on uranium alloy; Plutonium recovery and research;**
	Fabrication of pressure vessels

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Kansas City Plant
Kansas City, Missouri

Contractor: Allied-Signal

Principal Missions: Fabrication and assembly of electrical, electronic, electro-mechanical, precision mechanical, rubber and plastic components;
Heavy machining

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Y-12 Plant
Oak Ridge, Tennessee

Contractor: Martin Marietta

Principal Missions:
- Fabrication of test and stockpile secondary assemblies;
- Fabrication and research in uranium;
- Machining

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Pinellas Plant
St. Petersburg, Florida

Contractor:	**Martin Marietta speciality components, inc.**
Principal Missions:	**Neutron generators, thermal batteries, Radioisotopic Thermoelectric Generator (RTGs), lightning arrestor connectors, capacitors, neutron detectors**

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Savannah River Plant
Aiken, South Carolina

Contractor: Westinghouse

Principal Missions: Production of tritium and plutonium;
Fill reservoirs with tritium

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Pantex Plant
Amarillo, Texas

Contractor:	**Mason and Hanger**
Principal Missions:	**Fabricate high explosive system;** **Final assembly, disassembly and retirement of weapons**

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Historical Pressure on Nuclear Designs

	PEACETIME EMPHASIS	WARTIME EMPHASIS
IMPROVE	SAFETY SECURITY CONTROL	SURVIVABILITY DELIVERABILITY EFFECTIVENESS FLEXIBILITY BATTLE MANAGEMENT
REDUCE	MAINTENANCE MOVEMENT TRAINING	REACTION TIME OPERATIONAL CONSTRAINTS COLLATERAL DAMAGE

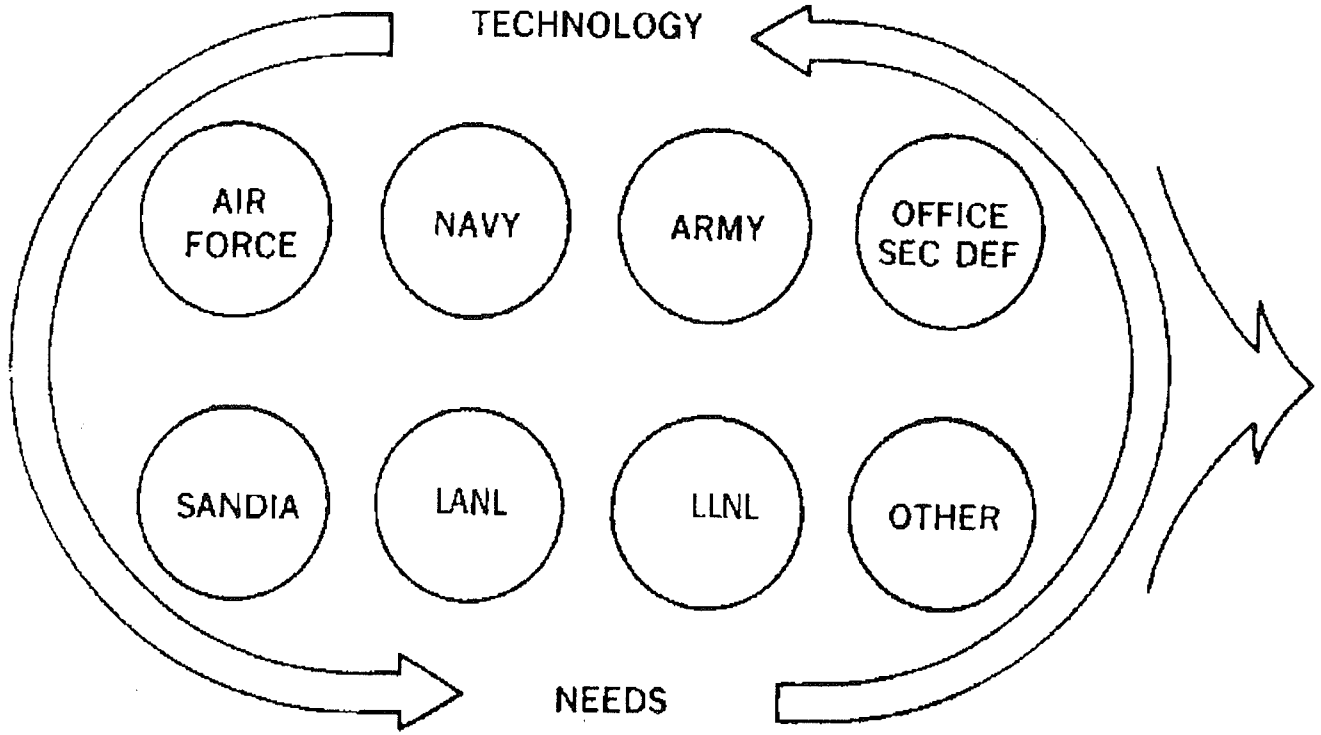
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PHASE 1 CONCEPT FORMULATION

(Φ1)



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Phase 1 - Weapon Conception

DOE

Continuing studies by DOE agencies. Studies may be informal and independent from DoD or may be conducted jointly with DoD. May result in the focusing of sufficient DoD interest in a modification of a present weapon or in the development of a new type weapon to warrant formal study.

DoD

Continuing studies by DoD agencies. May be independent of the DOE or may be conducted jointly with DOE. Sufficient attention may become focused on an item to warrant a formal program study. DoD requests DOE to make a program study on a new idea for a weapon or component or may initiate its own study.

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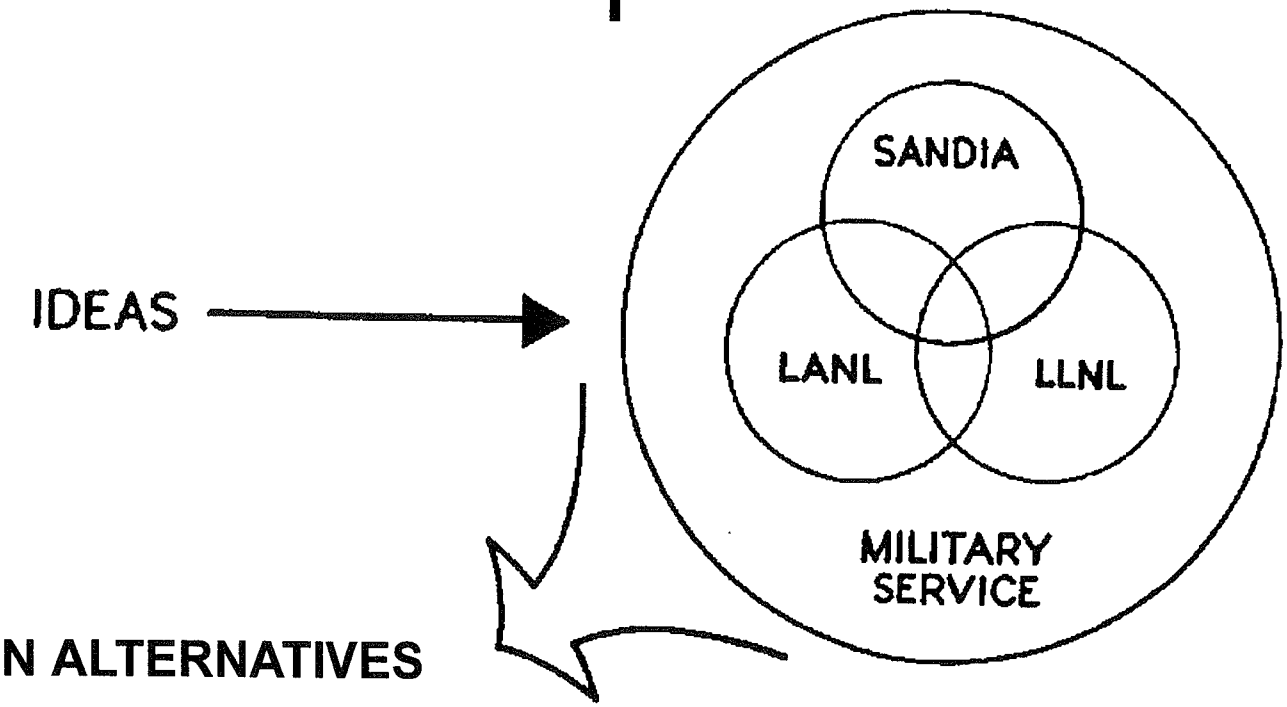
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PHASE 2 FEASIBILITY

(φ2)



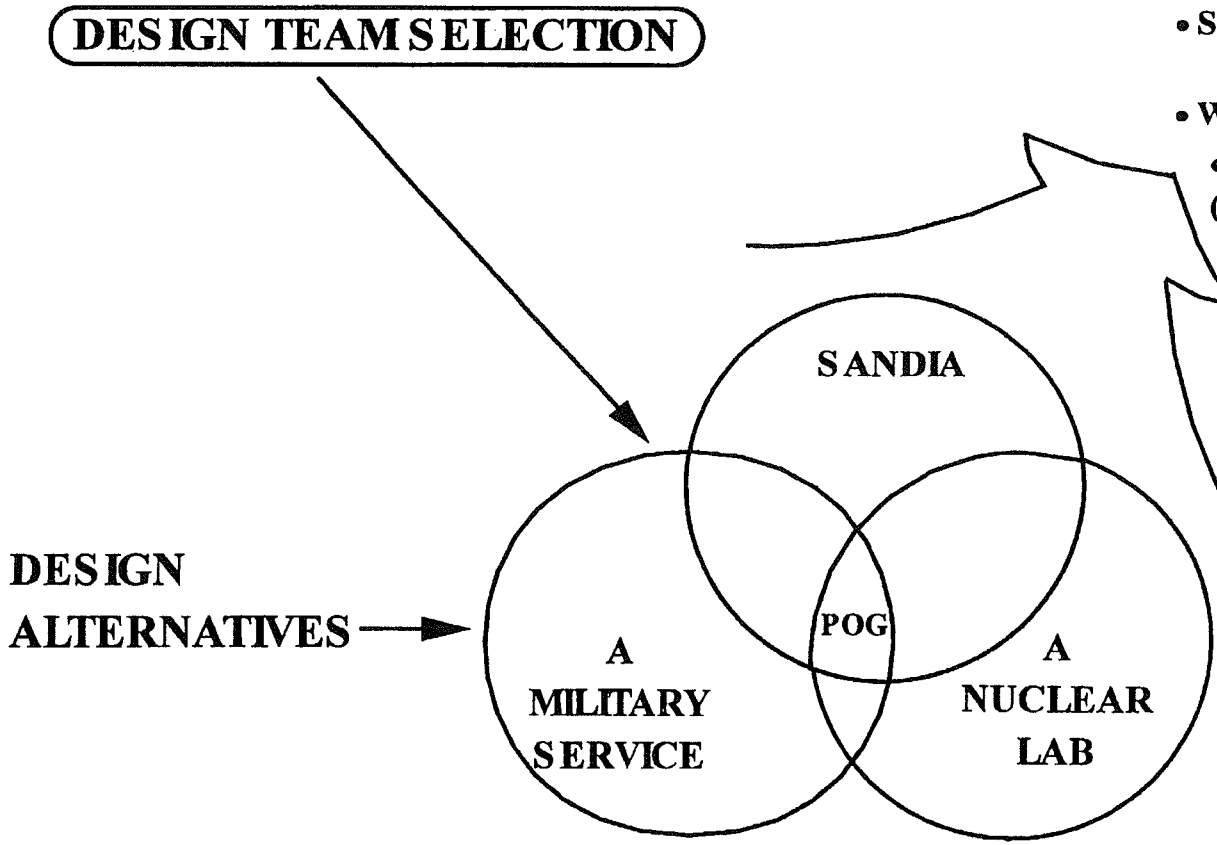
DESIGN ALTERNATIVES
MAJOR IMPACT
REPORT

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Phase 2A VALIDATION
(ϕ2A)

- SELECT BASELINE DESIGN & LAB
- SCHEDULE
- WEAPON DESIGN & COST REPORT (WDCR)



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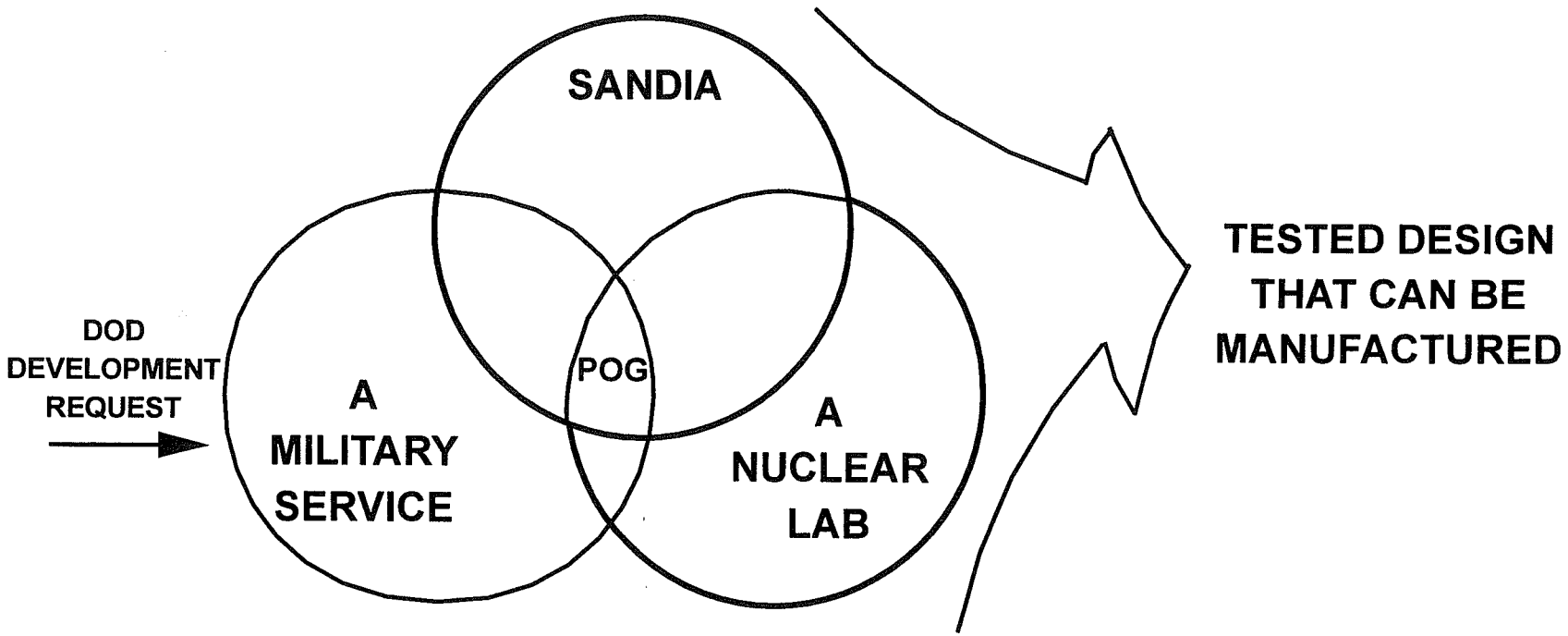
Phase 2A - Design Definition and Cost Studies

A DOE design team will normally be selected and a Project Officer Group will be formed. The POG will conduct trade-off studies to identify baseline design(s) which best balances resources and requirements. Review and revise draft MCs and STs. Establish tentative development and production schedule and division of responsibilities. A Weapon Design and Cost Report will be prepared.

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Phase 3 ENGINEERING DEVELOPMENT
(Φ3)



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Phase 3 - Development Engineering

DOE

Launches a development program based on required military characteristics. Produces prototypes for DOE and DoD evaluation.

Provides development specifications to DoD as they become available.

Determines the developmental design release date and submits a final report on the development design to the DoD.

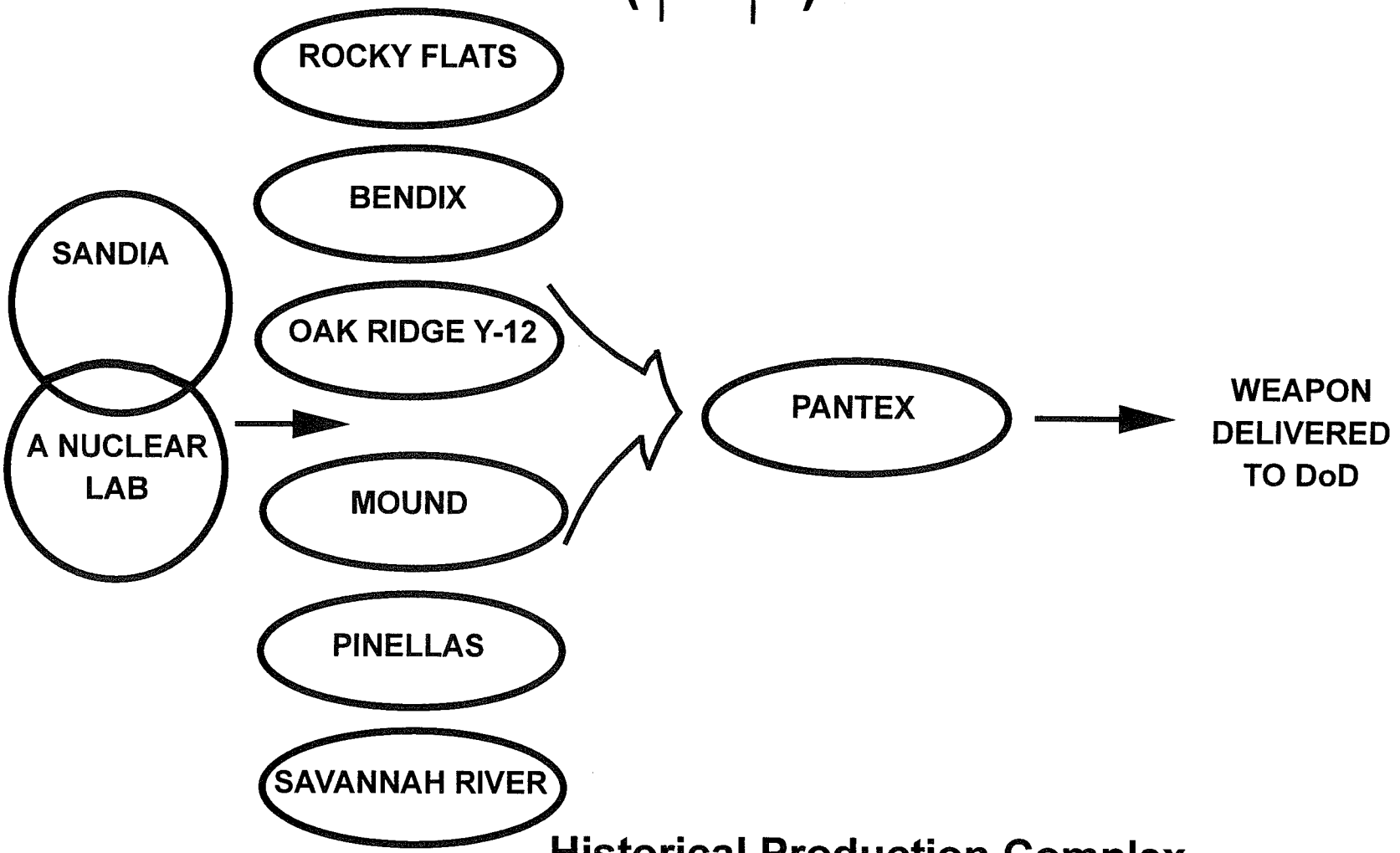
DoD

Maintains liaison with DOE field agencies and conducts independent evaluation of prototypes as considered necessary.

Studies the development specifications of the weapon design and gives appropriate guidance to the DOE.

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Phase 4-6 PRODUCTION
(Φ4-Φ6)



- Historical Production Complex
- Reconfiguration Will Impact

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Phase 4 - Production Engineering

DOE

Proceeds with production engineering of weapon, tooling, and layout of manufacturing facilities, without waiting for formal comments of DoD on the developmental design. Such guidance is integrated when received. Further prototype evaluation is performed during this phase.

Prepares product specifications for production release and furnishes these specifications to the DoD for review.

DoD

Reviews product specification.

Maintains liaison with appropriate DOE agencies on product design changes and specifications and gives appropriate guidance to DOE.

Continues evaluation of prototypes as considered necessary.

Phase 5 - First Production

DOE

Initiates manufacture of weapons according to product specifications by production tools, without waiting for DoD's comments on product specifications. DOE performs own evaluation and on basis of preliminary evaluation releases weapons to DoD for testing, training, and other purposes. Makes final evaluation and approves weapon model as suitable for standardization.

DoD

Completes operational suitability tests and makes independent evaluation of production type weapons. If weapon as designed, produced, and approved by DOE is satisfactory, approves the weapon as standard.

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Phase 6 - Quantity Production and Stockpile

DOE

Brings various production facilities up to full production pursuant to DoD requirements. Maintains production, inspection and quality control programs to ensure that each article produced meets specifications.

Maintains quality assurance and functional surveillance programs to ensure the continued quality of weapons in stockpile, in accordance with current agreements with respect to stockpile operations. These programs and the data obtained thereof will be made available to the DoD.

DoD

Maintains liaison with DOE agencies at production facilities. Continues appraisal of weapon performance.

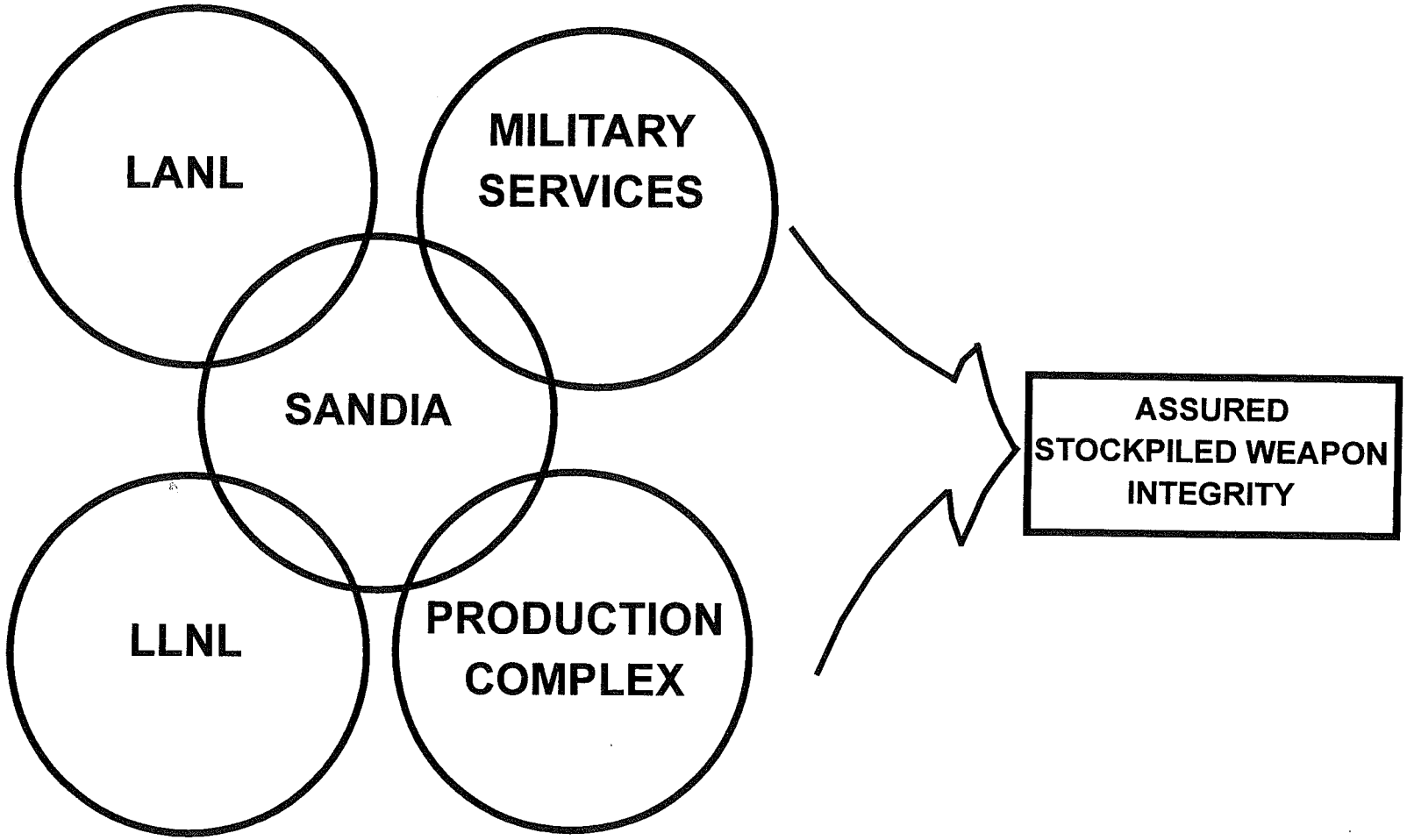
Maintains liaison with DOE to review performance and technical advances in anticipation of modernization changes.

Reviews DOEs quality assurance and functional surveillance programs and results and submits appropriate comments and recommendations to the DOE. Maintains functional surveillance program in accordance with current agreements with respect to stockpile operations.

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Phase 6 STOCKPILE SURVEILLANCE
(ϕ6)



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Nuclear Weapon Life Cycle

(The following pages are for reference. Not all of the material will be presented during the briefing)

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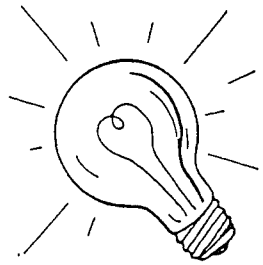
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WEAPON DEVELOPMENT

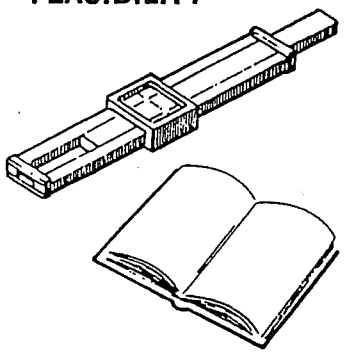
PHASE 1

CONCEPT DEFINITION



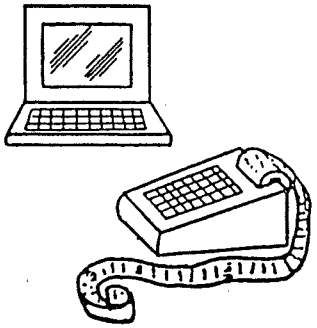
PHASE 2

FEASIBILITY



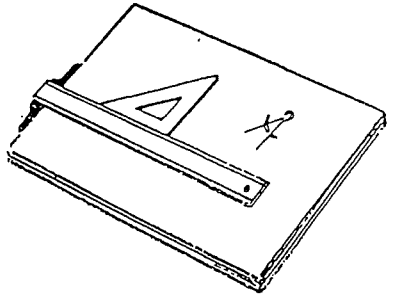
PHASE 2A

DESIGN DEFINITION AND COST



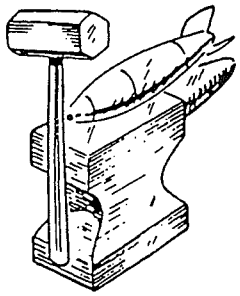
PHASE 3

DEVELOPMENT ENGINEERING



PHASE 4

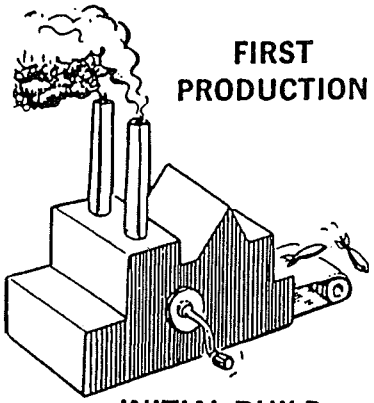
PRODUCTION ENGINEERING



PILOT PRODUCTION & TOOL MADE SAMPLE

PHASE 5

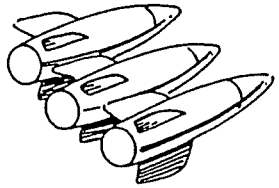
FIRST PRODUCTION



INITIAL BUILD AND EVALUATION

PHASE 6

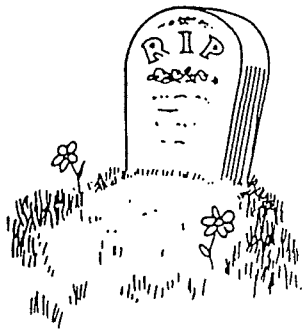
QUANTITY PRODUCTION & STOCKPILE



INITIAL OPERATIONAL CAPABILITY (IOC)

PHASE 7

RETIREMENT



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Phase 1 -- Concept Definition

Initiation: Informal agreement between participants to undertake study

Purpose: Study a Service requirement or DOE technological breakthrough/innovation for weapon application

Organization: Joint DoD/DOE Study Group with appropriate working groups. (Note: it can be a DOE or DoD-only study group.) Working Groups: Surety, Requirements Analysis, Mission Analysis, Warhead Design, and Systems Engineering

Deliverables: Phase 1 Study Report [In some cases: Draft Military Characteristics (MCs) & Draft Stockpile-to-Target Sequence (STS)]

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Phase 1 Activities

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Military Characteristics

- **Warhead performance requirements**
- **Warhead physical characteristics**
- **Requirements for nuclear safety**

Phase 1 Activities

Stockpile-to-Target Sequence

- Logistical employment concepts
- Operational employment concepts
- Normal & abnormal environments applicable to MC safety requirements

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Phase 1 -- Concept Definition

Initiation: Informal agreement between participants to undertake study

Purpose: Study a service requirement or DOE technological breakthrough/innovation for weapon application.

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Deliverables: Phase 1 study report [In some cases: Draft Military Characteristics (MCs) & Draft Stockpile-to-Target Sequence (STS)]

Duration & Cost: Normally 1 year and low cost

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Phase 2 -- Weapon Feasibility

Initiation:	**Formal request from DoD [ATSD (AE)] to DOE to participate with DoD in study.**
Purpose:	**Develop various weapon alternatives to fulfill service requirements.**
Organization:	**Joint DoD/DOE Study Group with appropriate working groups. [Sometimes a Project Office Group, (POG) is formed.] Working Groups: Surety, requirements analysis, mission analysis, warhead design, and systems engineering.**
Deliverables:	**Phase 2 study report with warhead alternatives** **Draft Military Characteristics (MCs)** **Draft Stockpile-to-Target Sequence (STS)** **Nuclear Safety & Use Control Themes** **Major Impact Report (MIR)** **Decision Cost Estimates**
Duration & Cost:	**Normally 2 years and low cost.**
Parallel DoD Activities:	**Milestone 1 Concept Demonstration Approval precedes Phase 2.**

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Phase 2A -- Design Definition & Cost

Initiation:	**Normal included as part of Phase 2 authorization. If not, then formal ATSD (AE) request to DOE is required**
Purpose:	**Develop a definitive cost estimate of the selected warhead design**
Organization:	**Formal Project Officers Group with appropriate subgroups. Subgroups: Safety & Surety, Maintenance & Logistics, Command & Control, Military Characteristics, Interface, and Stockpile-to-Target Sequence, among many**
Deliverables:	**Phase 2A Study Report** **Final Military Characteristics (MCs)** **Final Stockpile-to-Target Sequence (STS).** **DoD/DOE Memorandum of Understanding**
Duration & Cost:	**Normally 6 months and low cost**

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Phase 3 -- Development Engineering

Initiation:	**ATSD (AE) formally passes MCs, STS, and MOU to DOE/DP requesting their acceptance and requesting DOE participation in Phase 3 activities**
Purpose:	**Develop a finalized and tested weapon design that meets MC and STS criteria, and that can be produced by the DOE production complex**
Organization:	**Formal Project Officers Group with appropriate subgroups. Subgroups: Safety & Surety, Maintenance & Logistics, Command & Control, Military Characteristics, Interface, and Stockpile-to-Target Sequence, among many**
Deliverables:	**Phase 3 Study Report** **Final tested weapon design to include all required H & T gear.**
Duration & Cost:	**Normally 2.5 - 3 years and high cost**
Other Activities:	**DRAAG begins its activities, reviews PWDR. JNWPS manual begun**

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Phase 4 -- Production Engineering

Purpose:	**DOE production complex determines how it will produce the warhead. DOE production complex tools up necessary production lines**
Duration & Cost:	**Normally 2.5 years and high cost**
Other Activities:	**All weapons manual produced** **First generation training of military initiated** **DRAAG continues its activities, reviews IWDR**

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Phase 4 Activities

DOE Production Complex

Allied Signal, Kansas City Division

Location: Kansas City Missouri

DOE Contractor: Allied Signal Corporation

Product:

Non-nuclear electrical, electronic, electromechanical, mechanical, plastic, and nonfissionable metal components

Pinellas - Neutron detectors, LACs, among others

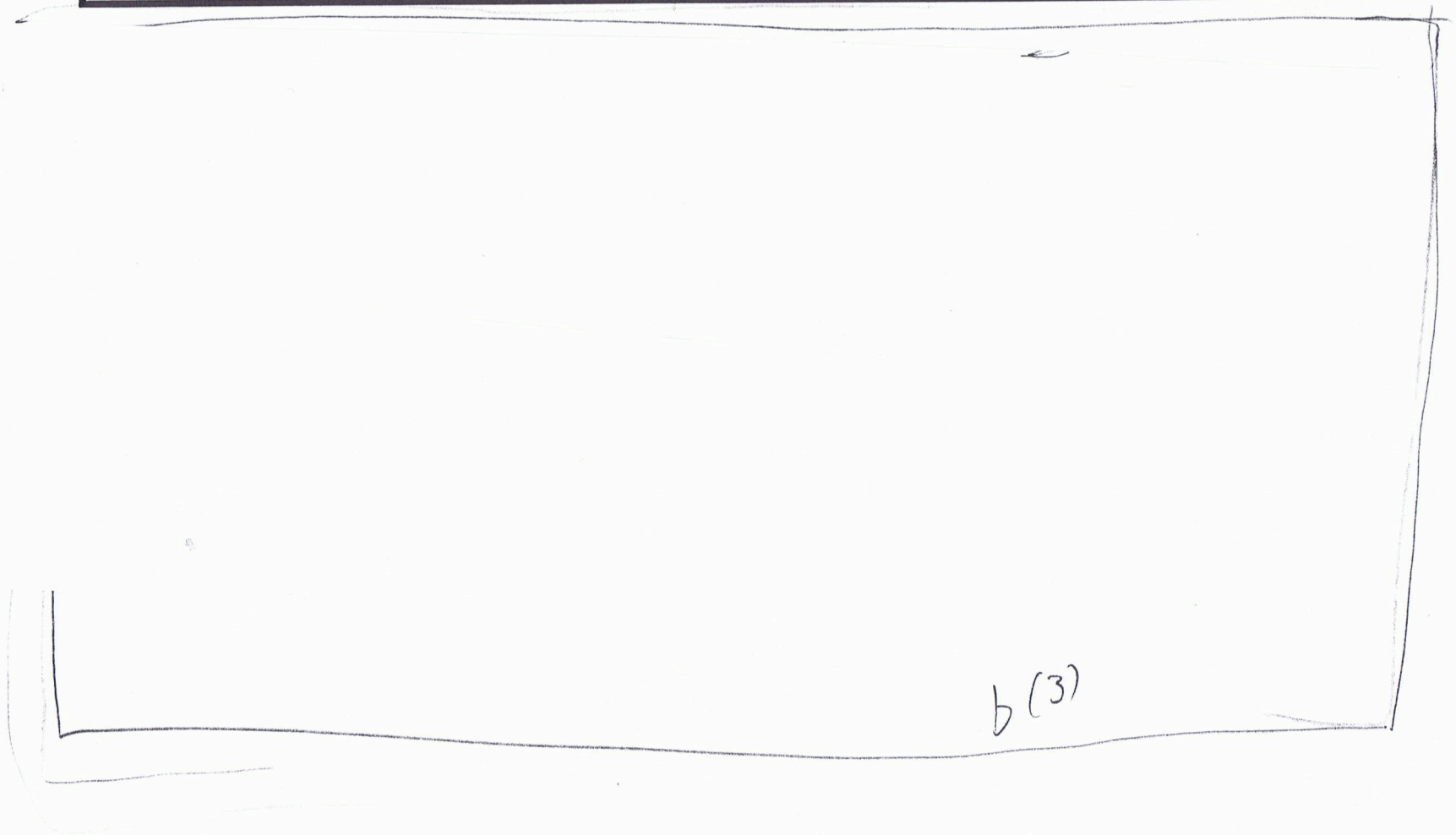
Rocky Flats - Reservoirs and SST construction

Mound - Flat & round cables and ACORNS

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Phase 4 Activities



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Phase 4 Activities

DOE Production Complex

Savannah River Plant

Location: Aiken, South Carolina

DOE Contractor: Westinghouse Corporation

Product:

Tritium, special isotopes, targets, and naval reactor fuel material

Fill boost reservoirs and ship them to the military

Mound - Gas transfer systems

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Phase 4 Activities

DOE Production Complex

Sandia National Laboratories

Location: Albuquerque, New Mexico

DOE Contractor: Lockheed-Martin Corporation

Product:

Pinellas - Thermal batteries, neutron generators, CAP assemblies, capacitors, and frequency devices/clocks

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Phase 4 Activities

DOE Production Complex

Los Alamos National Laboratory

- **Location: Los Alamos, New Mexico**
- **DOE Contractor: University of California**
- **Product:**
  - **Pinellas - Neutron tube target loading**
  - **Rocky Flats - Beryllium technology and pit support functions**
  - **Mound - High power detonators and calorimeters**

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Phase 4 Activities

DOE Production Complex

Pantex Plant

Location: Amarillo, Texas

DOE Contractor: Mason & Hanger

Product:

Explosive components

Assemble all nuclear weapons

Disassemble all weapons

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Phase 4 -- Production Engineering

Purpose:	**DOE Production Complex determines how it will produce the warhead. DOE Production Complex tools up necessary production lines**
Duration & Cost:	**Normally 2.5 years and high cost**
Other Activities:	**All weapons manuals produced** **First generation training of military initiated** **DRAAG continues its activities, reviews IWDR**

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Phase 5 -- First Production

Purpose:	**Produce initial products for new material evaluation testing. Refine production lines as a result of new material testing. Increase production rate to that required in Phase 6**
Duration & Cost:	**Normally 6 months and low cost**
Other Activities:	**DRAAG completes its activities. Nuclear certification of receiving service units**

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Nuclear Weapons Safety Study Group (NWSSG)

Chaired by Representative Service

Membership includes DOE, Defense Nuclear Agency, and representatives from Service Operational and Developmental Commands

Performs Safety Studies

- **Initial Safety Study - as early as possible in weapon development**
- **Pre-operational Safety Study - at least 120 days before IOC**
- **Operational Safety Review - within 2 yrs of fielding and every 5 yrs thereafter**
- **Special Safety Study - whenever system changes or problems require it**

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Phase 6 -- Quantity Production & Stockpile

Purpose: Produce War Reserve (WR) warheads in quantities directed by the Nuclear Weapons Stockpile Memorandum (NWSM) to support military IOC

Other Activities:

- Operational activities
- Logistics activities
- Nuclear accident/incident activities
- Technical inspections of nuclear-certified units
- Stockpile quality assurance and reliability testing
- Weapon modifications and retrofits
- Inactive stockpile

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Phase 6 Activities

Nuclear Weapon Operations

Nuclear weapon stockpile demonstrable element of nuclear deterrent strategy

- **Ability to employ effectively**
- **Surety**

Deployment

- **Peacetime threat** — **Peacetime storage**
- **Wartime threat** — **Wartime storage**

Employment

- **Rigorously controlled process**
- **Presidential release to a unified commander**
- **Conveyance of presidential release to executing commander**
- **Execution of nuclear mission by delivery units**

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Phase 6 Activities

Nuclear Weapon Operations (cont.)

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Command and Control

- Provides critical link and positive control by the President
- Designated communications systems
- Specific authentication procedures and codes

Training

- Ensure maximum unit and force readiness
- Exercises are still conducted

Personnel Reliability and Assurance Program

- Ensures highest possible standards of individual realiability
- DoD (PRP) DOE (PAP)

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Phase 6 Activities

Logistics Activities

Transportation

- Logistic movements (DOE and DoD)
- Operational movements (DoD)
- Safety and Security are important considerations

Storage

DOE DoD Security Areas

Maintenance

- Normally accomplished by the custodial service
- Accomplished at weapon storage area maintenance facilities or in maintenance trucks (USAFE)
- LLCE--boost reservoirs, neutron generators, RTGs

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Phase 6 Activities

Accident/Incident Activities

Nuclear Weapon Accident--unexpected event involving:

- **Accidental or unauthorized launching, firing, or use by US forces or U.S. supported allied forces of a nuclear capable system**
- **An accidental, unauthorized, or unexplained nuclear detonation**
- **Non-nuclear detonation or burning of a nuclear weapon or nuclear component**
- **Radioactive contamination**
- **Jettisoning of a nuclear weapon or nuclear component**
- **Public hazard, actual or perceived**

Nuclear Weapon Significant Incident--unexpected event involving:

- **Evident damage to a nuclear weapon**
- **Immediate action for safety or security**
- **Adverse public reaction**
- **A situation that could lead to a nuclear weapon accident**

Accident/Incident Response Preparation

- **DoD (EOD) and DOE (ARG) personnel continuously trained**
- **EOD manual and ARG procedures kept updated**
- **Joint DoD/DOE Accident/Incident training exercises held**

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Phase 6 Activities

Technical Inspections

Performed by Service or Field Command, Defense Nuclear Agency teams

Conducted at least annually

Used to recertify nuclear capable units

Emphasis on safety as well as operational requirements

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Phase 6 Activities

<u>Stockpile Quality Assurance and Reliability Testing</u>

Begun after the system has been in the field for a year

Consists of two types of testing:
- Stockpile Laboratory Testing (SLT)
- Stockpile Flight Testing (SFT)
- Used to include Stockpile Confidence Testing (SCT), but the UGT Moratorium has effectively canceled them

Each year test units chosen at random from the active stockpile

Test units disassembled at Pantex Plant
- Non-nuclear components tested via SLT and SFT
- One nuclear physics package testing non-nuclearly at physics lab

All but one test unit rebuilt and returned to the field

Each Service tests non-DOE system components

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Phase 6 Activities

Weapon Modification and Retrofits

Can be done in the field or at Pantex Plant

Modifications and retrofits usually incorporate new technology to increase weapon safety and/or reliability

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Phase 6 Activities

Inactive Stockpile (IS)

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DOD 6(2)
DOE 6(3)

Components may be stored to upgrade IS weapons to the status of the same weapons in the active stockpile

Phase 7-- Retirement

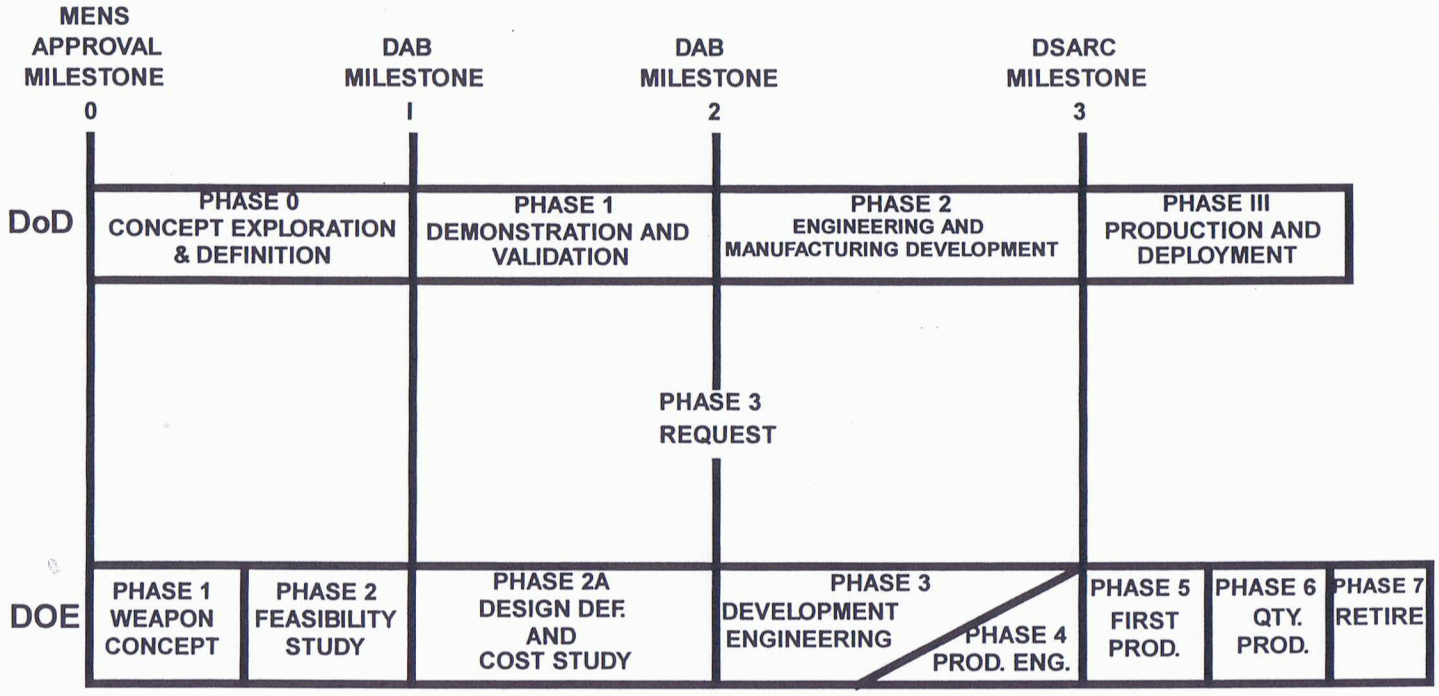
Purpose: To identify warheads to leave the active stockpile and to be dismantled by the Doe Productive Complex

Other Activities:

- Temporary storage of retired weapons by military is required as Pantex cannot accept all retired warheads
- Proper disposal of dismantlement waste stream
- Storage of nuclear components at Pantex due to inability to dispose of them
- Special nuclear material is reclaimed and retained

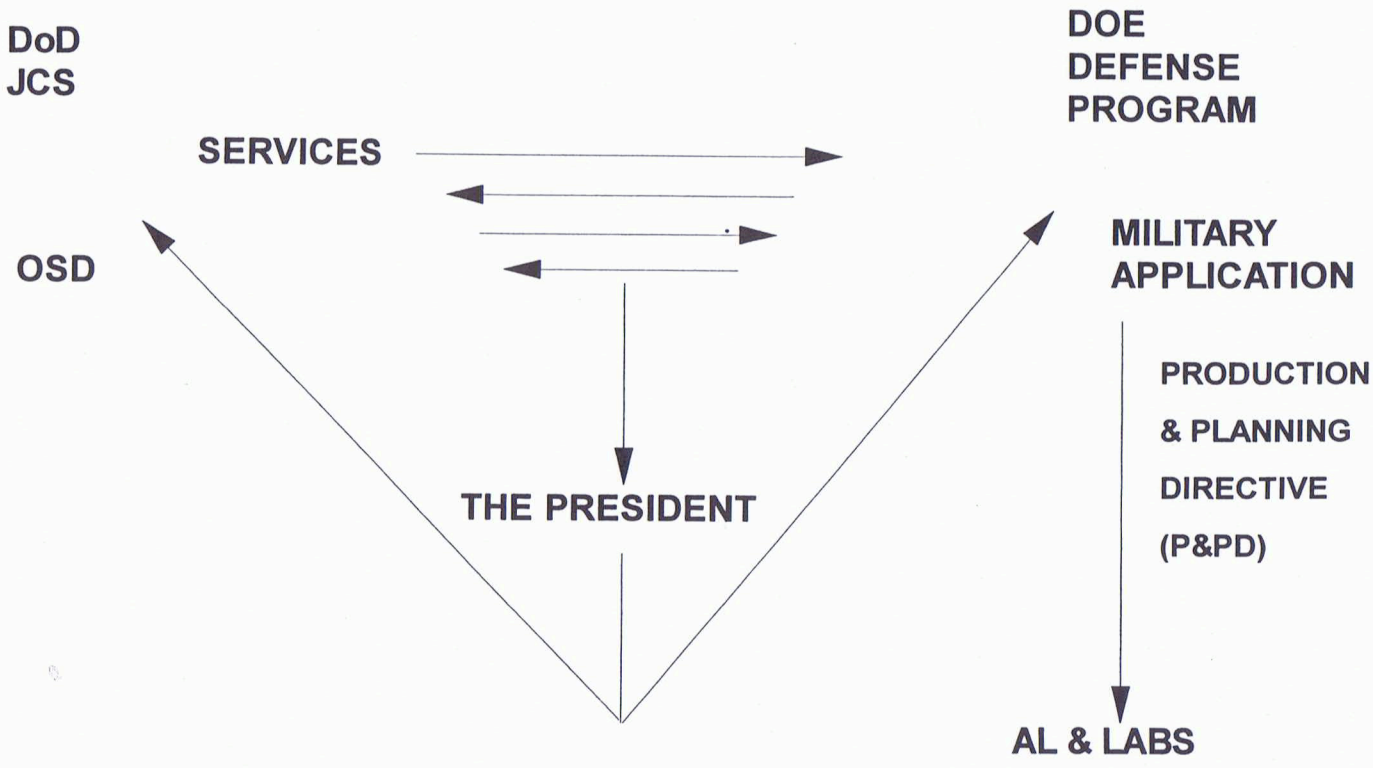
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DOD and DOE Acquisition



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ANNUAL STOCKPILE PAPER



LOOKS 11 YEARS AHEAD FOR PLANNING
AUTHORIZED 5 YEARS OF PRODUCTION
AND LONG LEAD PROCUREMENT
DoD & DOE MAY ADJUST UP TO 10%

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A MEMORANDUM OF UNDERSTANDING BETWEEN THE ERDA AND THE DoD ON NUCLEAR WEAPONS DEVELOPMENT LIAISON PROCEDURES. SEPT. 4, 1974.

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FUNDING AND MANAGEMENT ALTERNATIVES FOR ERDA MILITARY APPLICATION AND RESTRICTED DATA FUNCTIONS. ERDA 97, (SRD) JANUARY 1976.

PLANT MISSION POLICY, PART II ALO RS3172-3/08333.

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GLOSSARY

ABM	Anti Ballistic Missile
ACDA	Arms Control and Disarmament Agency
ADM	Atomic Demolition Munition
AEC	Atomic Energy Commission - then ERDA, now DOE
AF&F	Arming, Fuzing and Firing
AFAP	Artillery Fired Atomic Projectile
AFWL	Air Force Weapons Laboratory - now Phillips Laboratory
AK	Adaptation Kit
α	Alpha (Neutron Multiplication Rate)
ALCM	Air Launched Cruise Missile
AL	Albuquerque Operations Office
AMAC	Aircraft Monitor and Control
ASDP	Assistant Secretary (DOE) for Defense Programs
ATSD (AE)	Assistant to the Secretary of Defense for Atomic Energy
AWLPG	AL Workload Planning Guidance
Barn	Unit of cross section - 10^{-24} cm^2
Boosting	The use of deuterium/tritium to increase primary yield
Burnt Orange	The colors of a well-known outstanding university
CAT (A,B,C,D,E, or F) PAL	Permissive Action Link - code controlled open switch in the weapons arming circuit. Characteristics as defined in the "General Characteristics" of PAL definition
CD	Command Disable (locally initiated disablement of a nuclear weapon. Not, certficate of deposit, but can be command destruct

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CDU	Capacitor Discharge Unit
CEP	Circular Error Probable; circle within which 50% of the weapons are expected to hit
Channel	The space around the secondary and between the primary and secondary but inside the radiation case
CHE	Conventional High Explosive (means non-IHE)
CINC	Commander-in-Chief
CNWDI	Critical Nuclear Weapon Design Information - a DoD category of Secret RD information or higher pertaining to sensitive weapon design information; not, Caught Naked While Driving Intoxicated
Critical Mass	The minimum amount of fissionable material capable of supporting a chain reaction under precisely specified conditions
CTB	Comprehensive Test Ban
DAB	Defense Acquisition Board
DASMA	Deputy Assistant Secretary for Military Applications
Depleted Uranium	Uranium which has had much of the isotope U^{235} removed; essentially U^{238}
Destruct	Normally refers to the intentional destruction of a weapon by the high order detonation of the weapons HE at a single point
Disablement	Usually nonviolent actions taken on weapon hardware to prevent normal use. Disablement and destruct normally differ in degree
DMA	Directory of Military Application - now DASMA
DNA	Defense Nuclear Agency
DoD	Department of Defense
DRAAG	Design Review and Acceptance Group
EBW	Exploding BridgeWire (Detonator)
EMP	Electromagnetic Pulse

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EMR, EMI	Electromagnetic Radiation, Electromagnetic Interference
ENDS	Enhanced Nuclear Detonation Safety
Enhanced Electrical Safety	Embodiment of the exclusion region, strong-link, weak-link, unique signal concept (ENDS)
EOD	Explosive Ordnance Disposal
EP	Earth Penetrator
ER	Enhanced Radiation - usually neutron enhancement
ERDA	Energy Research Development Administration - was AEC, now DOE
ESD	Environmental Sensing Device
FEBA	Forward Edge of Battle Area - now FLOT
FLOT	Forward line of troops
FPU	First Production Unit
FRD	Formerly Restricted Data. Same as RD for foreign nationals
FRP	Fire Resistant Pit
Fuze	Component or subsystem that triggers the firing set. Use of fuse will likely bring abuse on you from old fuzing heads
FY	Fiscal Year
GLCM	Ground Launched Cruise Missile
HE	High Explosive
HOB	Height of Burst - vertical distance from the Earths surface to the point of burst
ICBM	Intercontinental Ballistic Missile
IFI	In-Flight-Insertion (mechanism)
IHE	Insensitive High Explosive - some form of TATB
INC	Insertable Nuclear Capsule
INF	Intermediate Range Nuclear Forces

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Interstage Area	The space between the primary and secondary
Intrinsic Radiation	Naturally occurring neutron and gamma radiation present at the surface of a weapon
IOC	Initial Operational Capability
JAIEG	Joint Atomic Information Exchange Group
JCAE	Joint Committee Information Exchange Group
JCS	Joint Chiefs of Staff
JTA	Joint Test Assembly
kT	Kiloton equivalent of TNT hydrodynamic yield
LANL	Los Alamos National Laboratory
Lay-down	A form of weapon delivery and/or fuzing. Parachute delivered bomb from very low altitudes with delayed groudburst using a timer fuze
Limited Stockpile Item	A stockpiled weapon which has not been accepted as a "standard" item and for which the DoD has requested additional development
LLC	Limited Life Component; component which must be periodically replaced due to aging
LLNL	Lawrence Livermore National Laboratory
LPO	Lead Project Officer
LRNTF	Long Range Theater Nuclear Forces
MA	Military Application (DOE) - usually refers to the DASMA office or staff
MAR	Major Assembly Release; SNL prepared, AL approved statement that war reserve weapon material is satisfactory for release on a designated date to the DoD for specified use qualified by exceptions and limitations
MIR	Major Impact Report
MIRV	Multiple Independently Targetable Reentry Vehicle

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Mk#	Mark Number. The system of certifying nuclear weapons and RV/RBs, cars, and other assorted goods (like TV programs!) For nuclear weapons - now replaced by W for Warhead and B for Bomb or other
MLC	Military Liaison Committee - historically was the coordinating and interchange of information focus between DoD and DOE
MRR	Minimum Residual Radiation - now RRR
MRV	Multiple Reentry Vehicle
MT	Megaton, million tons equivalent TNT. Also metric tons - 1000 kilograms

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OMA	Office of Military Application - now office of DASMA
OMB	Office of Management and Budget
One Point	The detonation of the weapon HE at a single point

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Oy	Oralloy - Oak Ridge Alloy. Uranium enriched in the isotope U^{235} to 93.5%
OSD	Office of the Secretary of Defense
PL	Phillips Laboratory (formerly Air Force Weapons Lab)
PAL	Permissive Action Link - coded use control feature
PA&E	Program Analysis and Evaluation, OSD, (not program annihilation and elimination)
P&PD	Production and Planning Directive
P&S	Production and Surveillance
PM-NUC	Program Manager - Nuclear Munitions (Army program office for nuclear-no longer active)
POC	Programs of Cooperation
POG	Project Officers Group
POM	Meeting of the POG
Primary	The "fission" device
Pu	Plutonium, a reactor produced fissionable material obtained by bombarding U^{238} with neutrons
QA	Quality Assurance - DoD uses QART—Quality Assurance, Reliability Testing
QRA	Quick Reaction Alert; weapon system deployed in a state that would allow its employment in a stated minimum specified time
RB	Reentry Body - Navy term for RV
RD	Restricted Data; all data concerning design, manufacture, or utilization of nuclear weapons and the production of special nuclear material which has not been removed by the Atomic Energy Act of 1954
Rolomite	A Sandia designed ESD sensor
RRR	Reduced Residual Radiation - reduced fission devices—formerly MRR (Minimum Residual Radiation)
RTG	Radioisotopic Thermoelectric Generator

RV	Reentry Vehicle Army, Air Force - Navy calls them RBs, definitely not a recreational vehicle
SAC	Strategic Air Command
Secondary	The "thermonuclear" device
Sec Def	Secretary of Defense
Shake	10^{-8} seconds
SLBM	Submarine Launched Ballistic Missile
SLCM	Sea Launched Cruise Missile
SNL	Sandia National Laboratories
SNM	Special Nuclear Material - Pu, Oy
SP	Strategic Programs - Navy SLBM office
Specified Command	Combat command with a broad and continuing mission - usually a single service such as the Strategic Air Command
SRAM	Short Range Attack Missile
SS Material	Source Strength Material - DOE audits one kilogram quantities (includes depleted and natural uranium)
SSPO	Strategic Systems Program Office - now SP
Standard Stockpile Item	A nuclear weapon which meets the approved military characteristics to DoD"s satisfaction
Stockpile Nuclear Test	QA test of a system withdrawn from the stockpile. That rare instance that a stockpiled weapon is tested downhole at NTS - a stockpile "confidence test"
STS	Stockpile-to-Target Sequence
TATB	Triamino-Trinitro-Benzene; see IHE
TTR	Tonopah Test Range - Sandia's testing range at Tonopah, Nevada

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TREE	Transient radiation effects on electronics
Tritium	Third isotope of hydrogen, radioactive gas used to boost weapons
TTBT	Threshold Test Ban Treaty
Tu	Tuballoy - natural uranium. Sometimes also includes depleted uranium, i.e., essentially U^{238}
V– γ Map	A contour depicting permissible velocity and reentry angle combinations for a missile RV/RB
Unified Command	A combat command with a broad and continuing mission composed of forces of two or more services under a single commander
USANCA	U.S. Army Nuclear and Chemical Agency
USDR&E	Under Secretary of Defense for Research and Engineering
WR	War Reserve nuclear weapons material (in DOE or DoD custody) intended for employment in the event of war
Weapons Grade Pu	Plutonium which has 6% or less Pu^{240} content; Pu^{239} is the good stuff
WDCR	Weapon Design and Cost Report
WES	Warhead Electrical System
WS^3	Weapon Secure, Safe, Storage
WSV	Weapons Storage Vault (Weapons Security Vault)
X-unit	A device used to provide energy to initiate nuclear system detonators

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WEAPONS/WEAPON APPLICATIONS

WEAPON*	APPLICATION	SERVICE
FATMAN	BOMB	AF
LITTLEBOY	BOMB	AF
Mk III	BOMB	AF
Mk 4	BOMB	AF
T-4	ATOMIC DEMONITION MUNITION	A
Mk 5	BOMB	AF,N
Mk 5	MATADOR	AF
Mk 5	REGULUS I	N
Mk 6	BOMB	AF
Mk 7	BOMB	AF,N
Mk 7	HONEST JOHN	A
Mk 7	CORPORAL	A
Mk 7	BOAR	N
Mk 7	BETTY	N
Mk 7	ATOMIC DEMONITION MUNITION	A
Mk 7	NIKE HERCULES	A
Mk 8	BOMB	N
Mk 9	280-mm AFAP	A
Mk 11	BOMB	N

*Absence of entry indicates system not fielded

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WEAPON	APPLICATION	SERVICE
Mk 12	BOMB	AF,N
Mk 14	BOMB	AF
Mk 15	BOMB	AF,N
Mk 17	BOMB	AF
Mk 18	BOMB	AF,N
Mk19	280-mm AFAP	A
Mk21	BOMB	AF
Mk23	16" AFAP	N
B24	BOMB	AF
W25	GENIE	AF
B27	BOMB	N
W27	REGULUS I	N
B28	BOMB	AF,N
W28	HOUNDDOG	AF
W28	MACE	AF
W30	TALOS	N
W30	ATOMIC DEMONITION MUNITION	A
W31	HONEST JOHN	A
W31	NIKE HERCULES	A
W31	ATOMIC DEMONITION MUNITION	A
W33	8" PROJECTILE	A,N

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WEAPON	APPLICATION	SERVICE
W34	LULU	N
W34	ASTOR	N
B34	HOTPOINT	N
B36	BOMB	AF
W38	ATLAS	AF
W38	TITAN I	AF
B39	BOMB	AF,N
W39	B-58 pod	AF
W39	REDSTONE	A
W39	SNARK	AF
W40	BOMARC	AF
W40	LACROSSE	A
B41	BOMB	AF
B43	BOMB	N,AF
W44	ASROC	N
W45	BULLPUP	N
W45	TERRIER	N
W45	LITTLE JOHN	A
W45	MADM	A
W47	POLARIS	N
W48	155-mm AFAP	A,N

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WEAPON	APPLICATION	SERVICE
W49	ATLAS	AF
W49	THOR	AF
W49	JUPITER	A,AF
W49	TITAN I	AF
W50	PERSHING	A
W50	NIKE ZEUS	A
W52	SERGEANT	A
W53	BOMB	AF
W53	TITAN II	AF
W54	FALCON	AF
W54	DAVY CROCKETT	A
W54	SADM	A,N
W55	SUBROC	N
W56	MINUTEMAN	AF
B57	BOMB/DEPTH BOMB	AF,N
W58	POLARIS A3	N
W59	MINUTEMAN I	AF
B61	BOMB	AF,N
W62	MINUTEMAN II	AF
W66	SPRINT	A
W68	POSEIDON C3	N
W69	SRAM	AF

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WEAPON	APPLICATION	SERVICE
W70	LANCE	A
W71	SPARTAN	A
W72	WALLEYE	AF
W76	TRIDENT I	N
W78	MINUTEMAN III	AF
W79	8" AFAP	A,N
W80	SLCM	N
W80	ALCM	AF
B83	BOMB	AF
W84	GLCM	AF
W85	PERSHING II	A
W87	PEACEKEEPER ICBM	AF
W88	TRIDENT II	N

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

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SESSION II

- REVIEW OF WEAPONS PHYSICS
- THEORY OF NUCLEAR EXPLOSIONS

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Weapons Physics and Nuclear Material

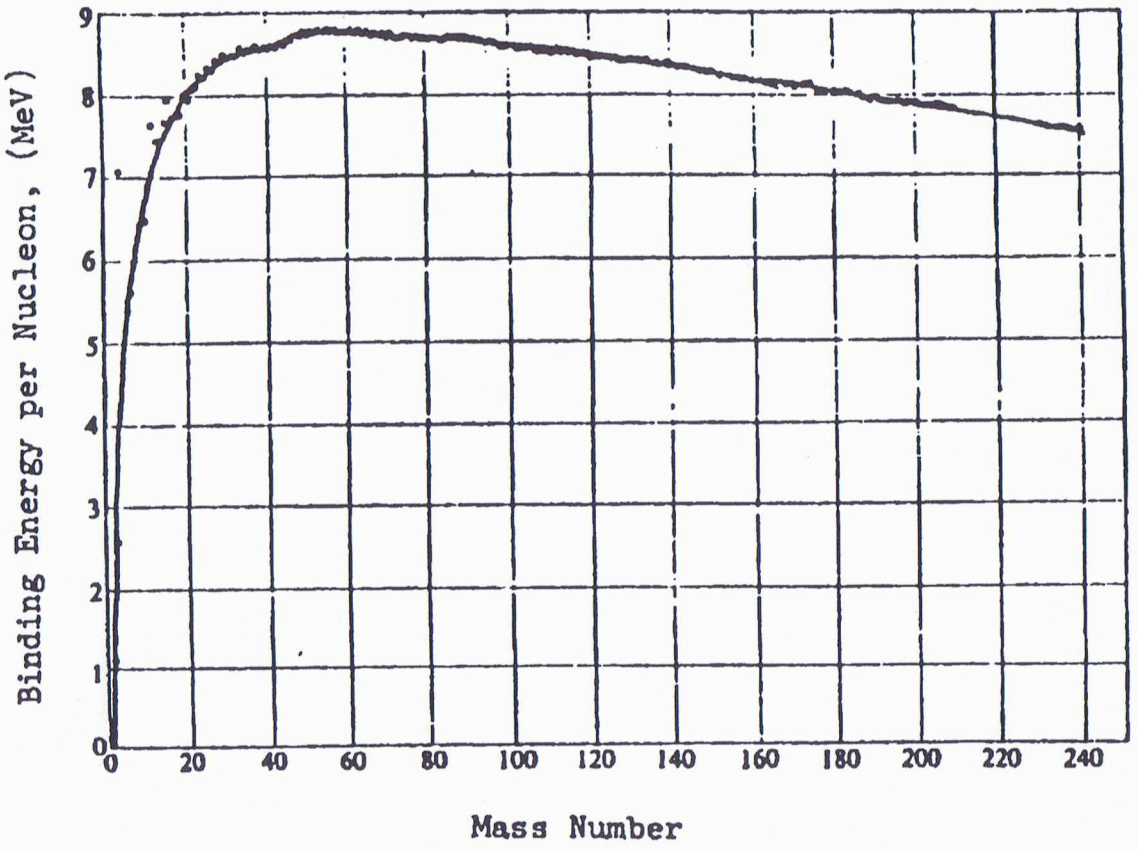
- Several basic nuclear physics concepts and the properties of the nuclear fissile material are very important to the understanding of weaponization
- The physics of fission
- Nuclear properties
- Availability of material
- How the fissile material is obtained
- Energy available and energy trades

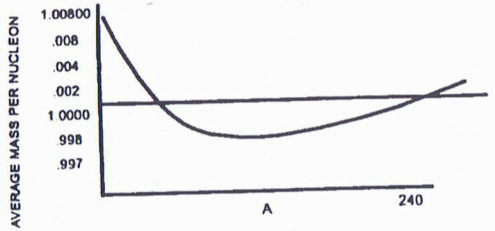
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NUCLEAR BINDING ENERGY

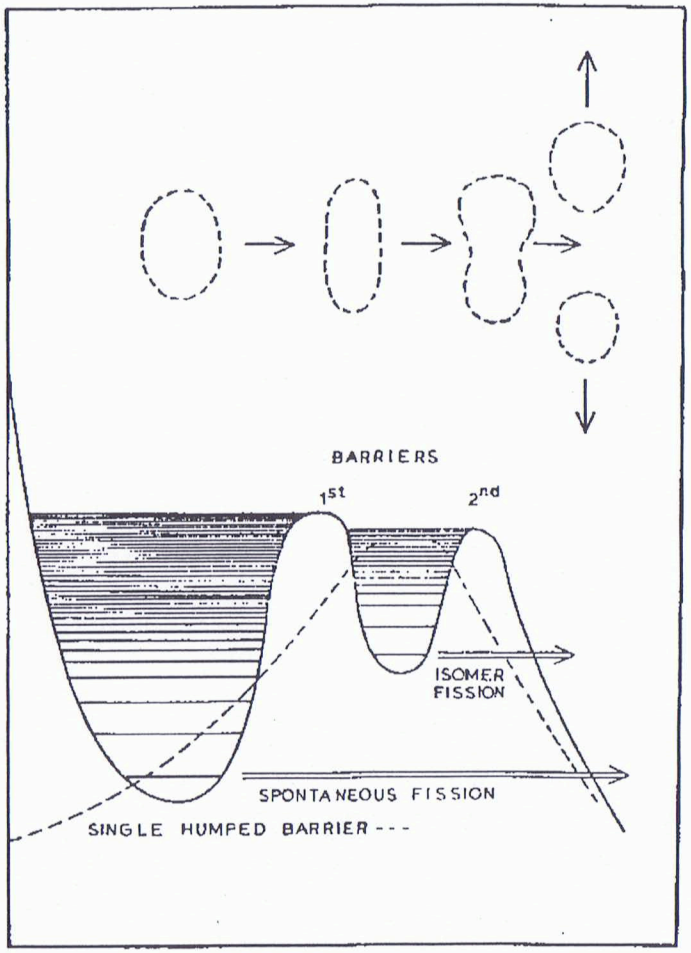




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LIQUID DROP MODEL APPLIED TO POTENTIAL BARRIERS



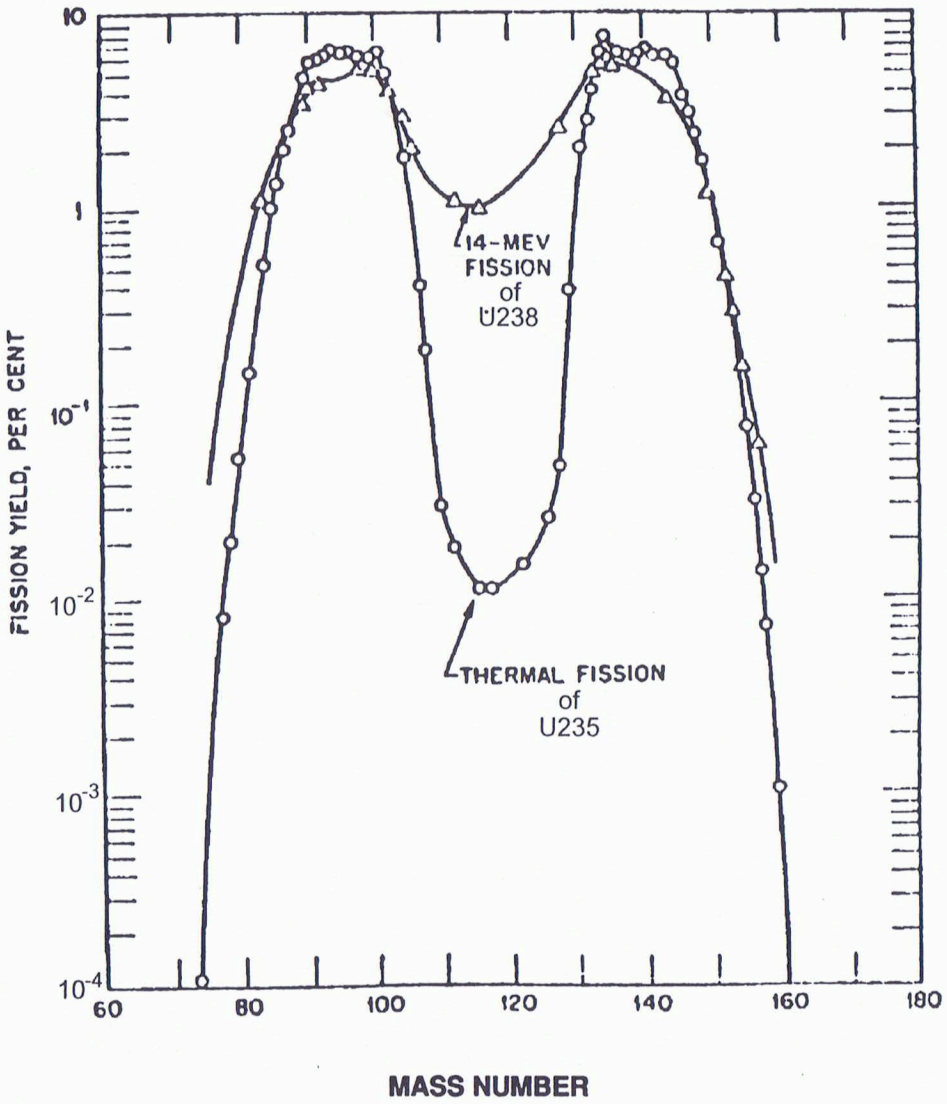
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CHARGE DISTRIBUTION CURVE

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LIKELIHOOD FOR FISSION FRAGMENT

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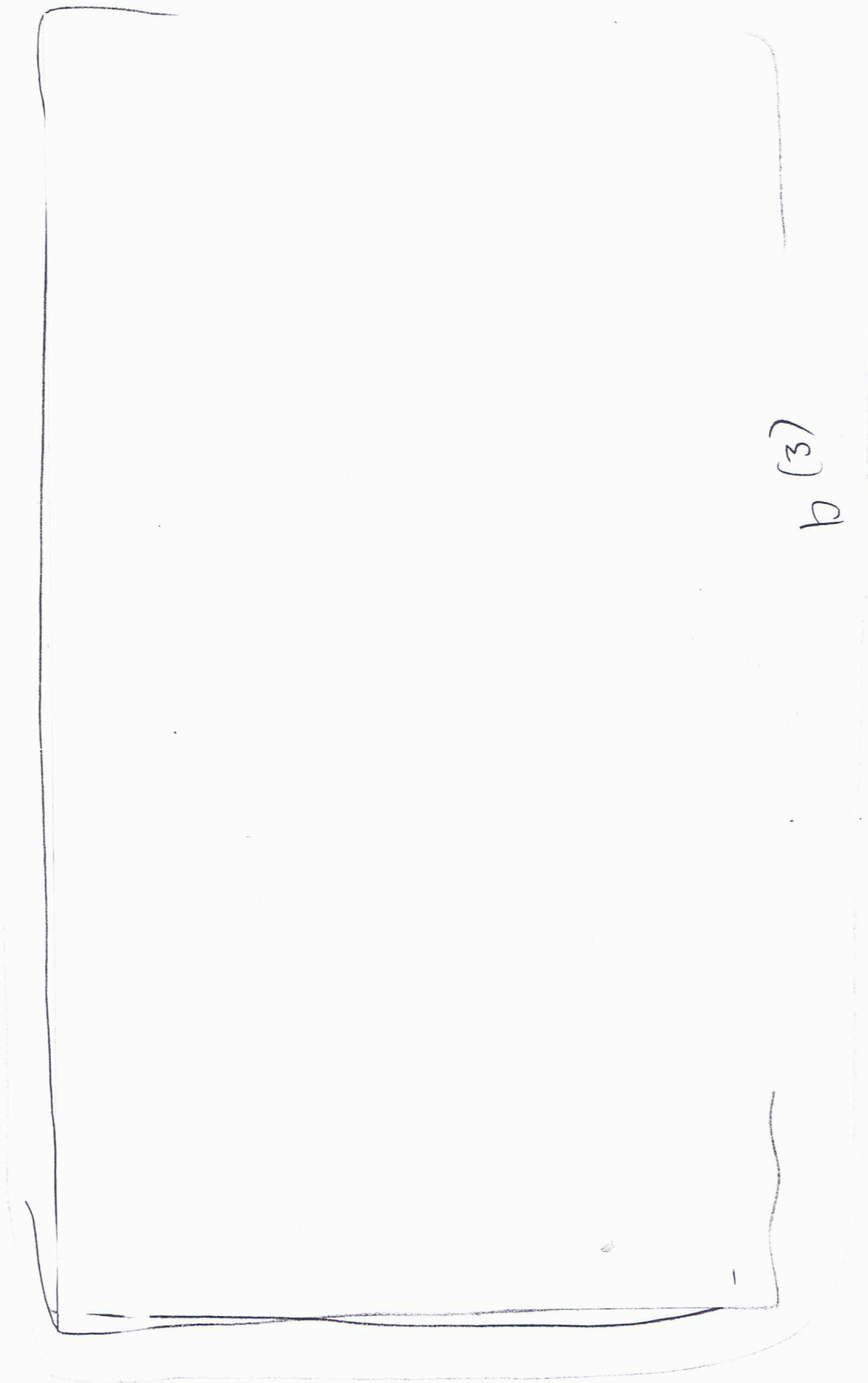
Terminology

Asymmetric fission	-	**division of excited nucleus into two unequal fragments with masses about 100 & 140 ama.**
Binary	-	**division at scission point into two parts.**
Cross-Section	-	**probability that a certain reaction between a nucleus and an incident particle or photon will occur, as in a neutron and U^{235} (measured in "barns")**
Fission Fragment	-	**fragment after scission but before prompt neutron emission**
Fission Product	-	**fragment after prompt neutron emission**

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DOE b(3)



b(3)

b (3)

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The Gang of Four

$^{238}U_{92}$ % in nature - 99.27 When the $^{238}U_{92}$ is extracted, it is called depleted ^{238}U or TUBALLOY or D38 (from UK WWII effort - TUBE ALLOY) Will fission but not fissile Physically separated	^{239}Pu % in nature - essentially zero (mine in South Africa) Made in reactor: $n + {}^{238}U = {}^{239}Pu$
^{235}U % in nature - 00.73 Concentrated to 93.5% Called ORALLOY for Oak Ridge Alloy	^{240}Pu % in nature - essentially zero Made by reactor If you leave the ^{239}Pu in "too long," it will absorb a n ➡ ^{240}Pu Spontaneously fissions (originally a problem for pre-ignition)

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CALCULATION OF ENERGY RELEASE

$$_{92}U^{235} + {}_{o}n^{1} \longrightarrow {}_{42}Mo^{95} + {}_{57}La^{139} + {}_{-1}e^{o} + 2\,{}_{o}n^{1}$$

235.0439	94.905837
1.0087	138.906400
	.003850
	2.017340
236.0526 amu ⟶	235.8334 amu atomic mass unit

MASS DEFECT OF .219 amu

n = 1.00867 amu
p = 1.00728 amu
e = .00055 amu

$$(.219 \text{ amu}) \quad \left(931.4 \frac{\text{MeV}}{\text{amu}}\right) \simeq 204 \text{ MeV}$$

THE EXAMPLE STARTED WITH

$$_{54}Xe^{139} \xrightarrow{3\,ß} {}_{57}La^{139} \quad \text{AND} \quad {}_{38}SR^{95} \xrightarrow{4\,ß} {}_{42}Mo^{95}$$

FISSION CHAIN

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THEORETICAL FISSION ENERGY

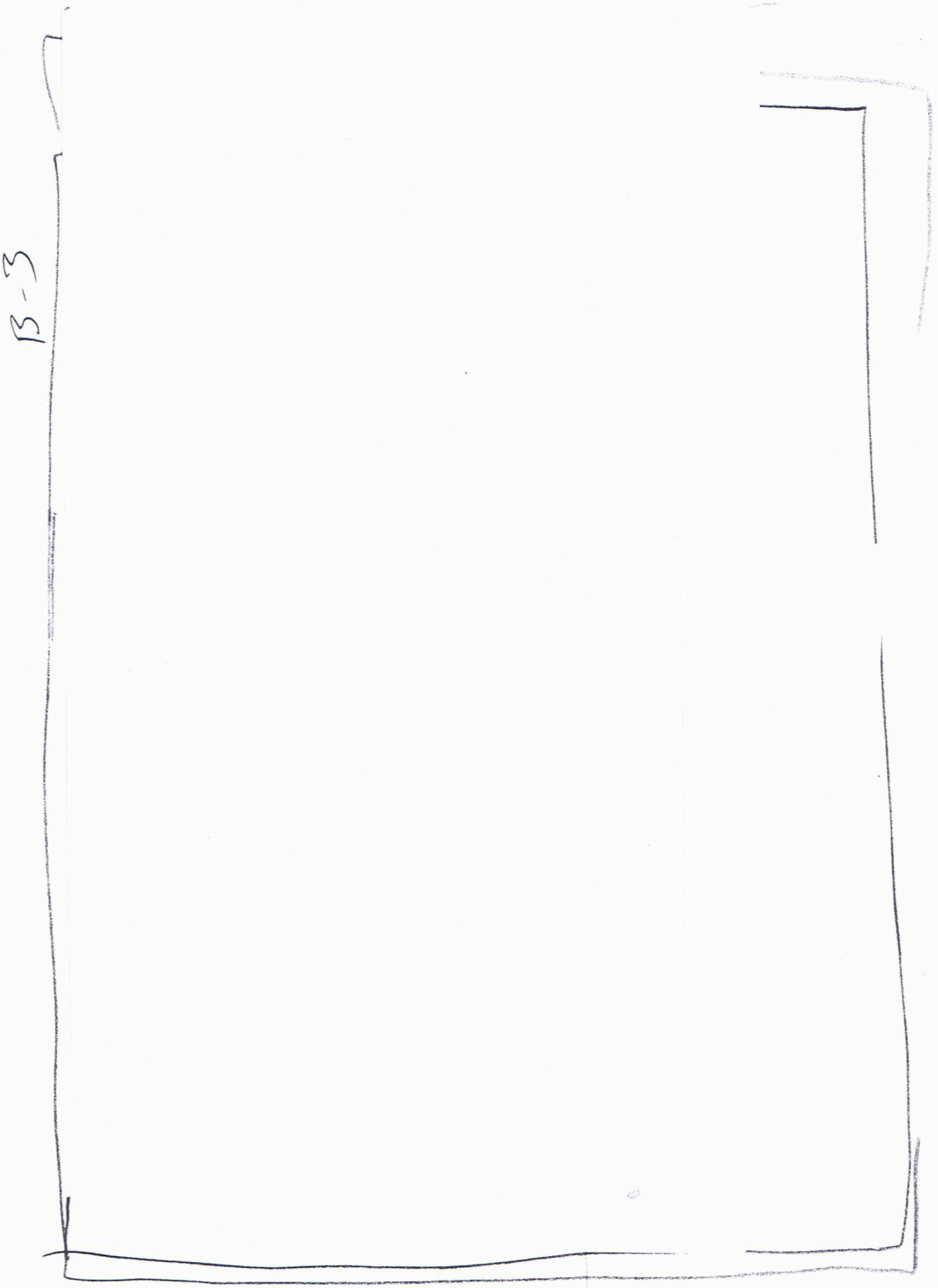
- THERE ARE $\frac{6.025 \times 10^{23}}{235.0439}$ ATOMS PER GRAM OF $_{92}U^{235}$
- THEREFORE, 1 kg OF $_{92}U^{235}$ HAS 2.5634×10^{24} ATOMS
- HENCE, @ 180 MeV PER FISSION 1 kg OF $_{92}U^{235}$ WOULD PRODUCE 4.6141×10^{26} MeV IF EACH ATOM WERE FISSIONED.
- CONVERTING TO KILOTONS
- $(4.6141 \times 10^{26}\ \text{MeV})\ (3.824 \times 10^{-26}\ \frac{\text{kT}}{\text{MeV}}) \simeq 18\ \text{kT}$

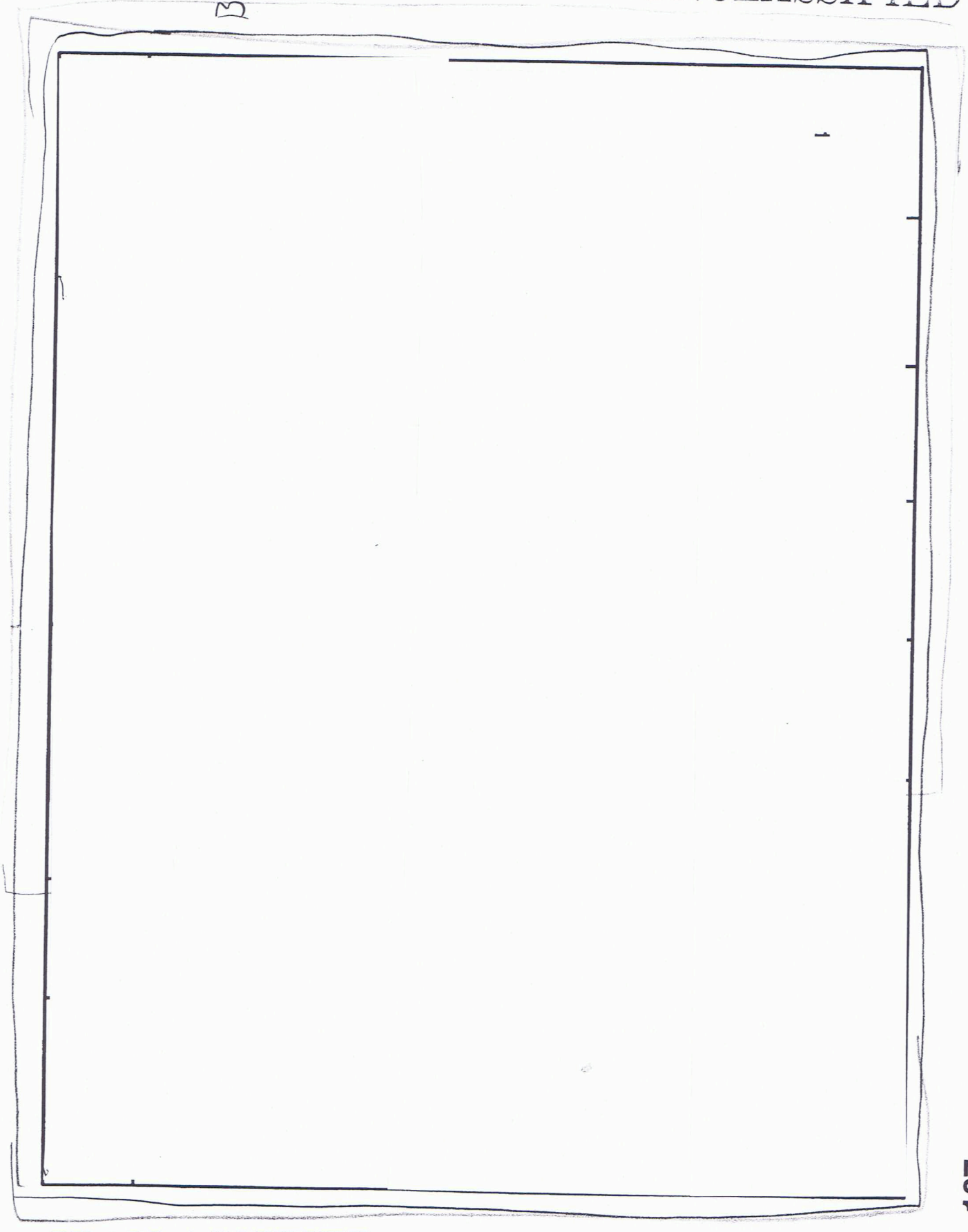
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FACTORS AFFECTING CRITICAL MASS

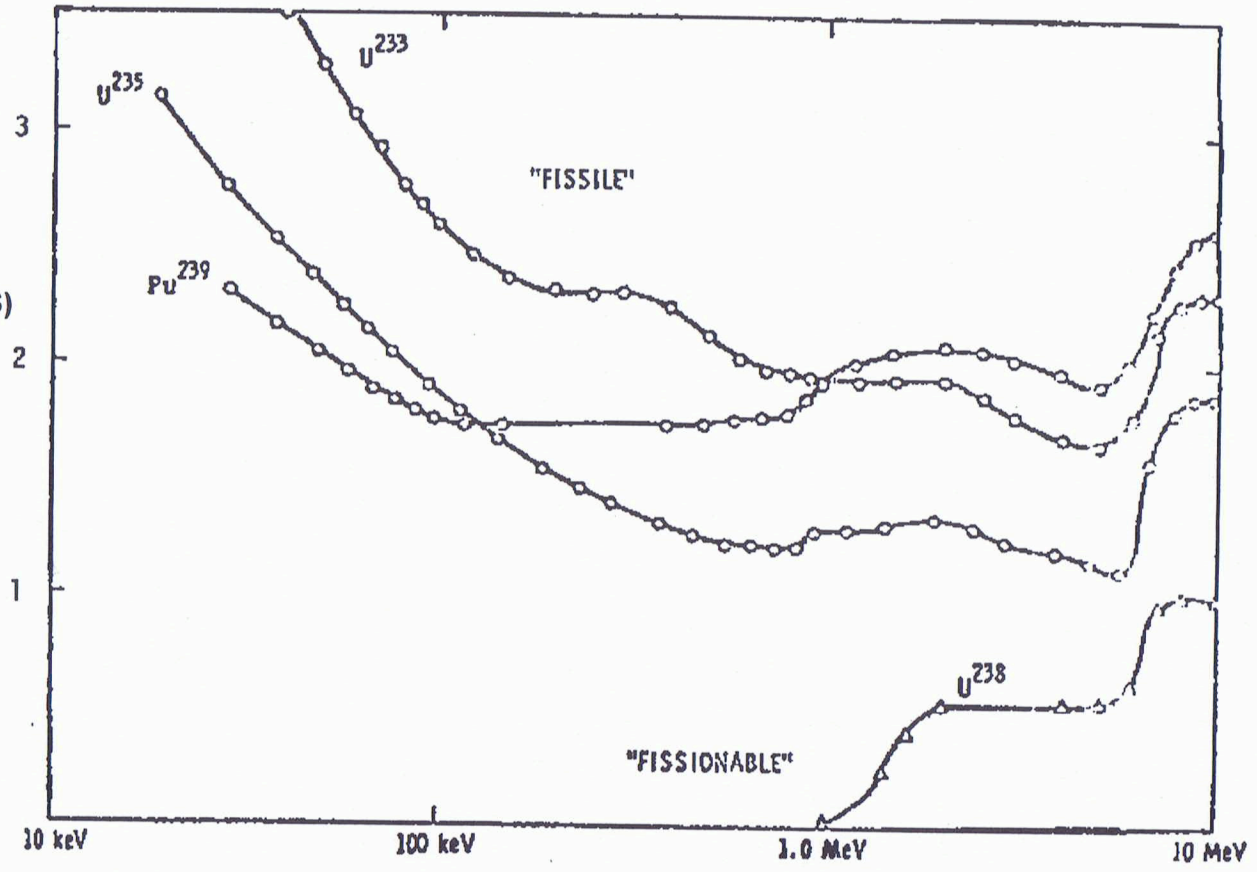
- GEOMETRY
- AMOUNT OF MATERIAL
- TYPE OF MATERIAL
- PURITY OF MATERIAL
- SURROUNDING MATERIAL
- DENSITY

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FISSION CROSS SECTIONS



INCIDENT NEUTRON ENERGY

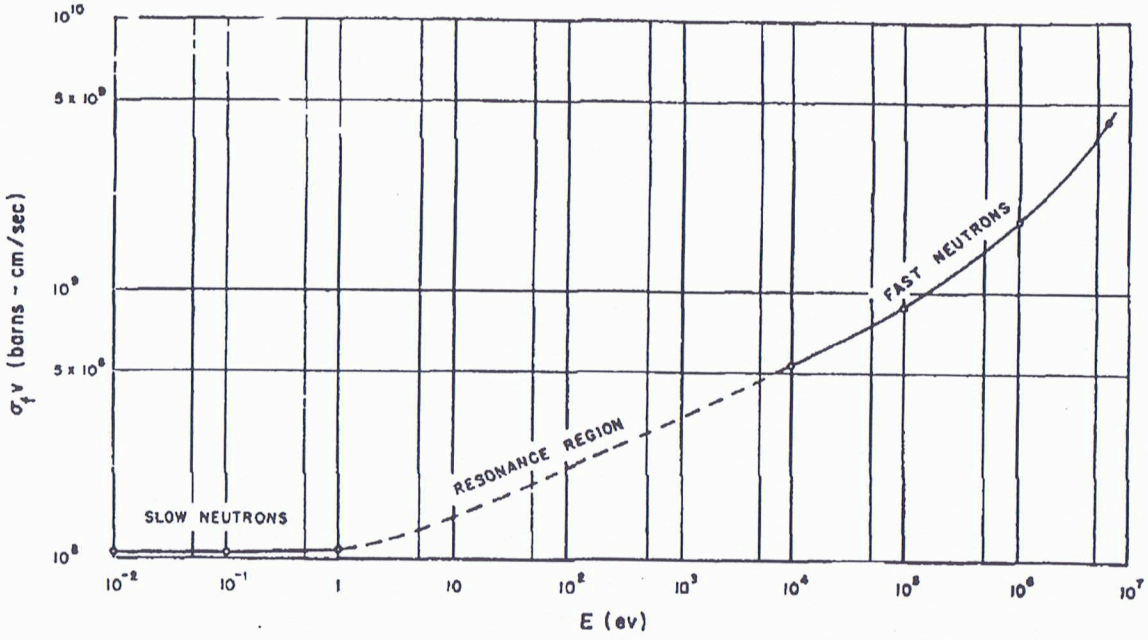
NOTE: The thermal neutron energy is not on the chart

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Variation of Cross Section x Ave. # Neutrons for ^{235}U



Neutron Energy

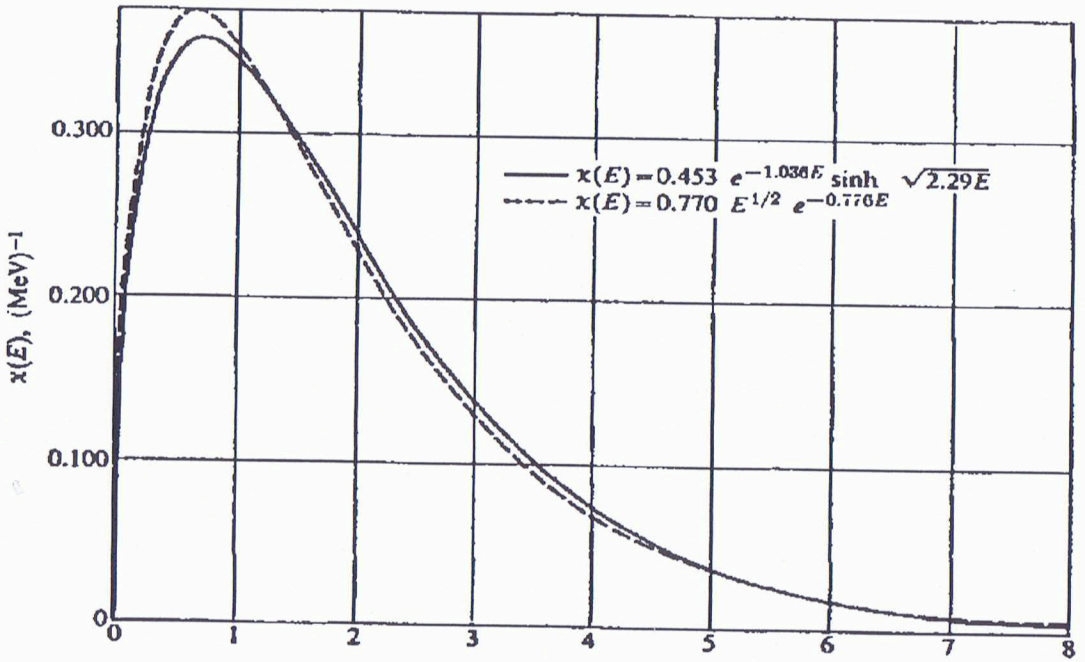
Fission is more effective at higher energies N

Smallest fission generation time at high energies ($T = 1/N\sigma_f \cdot v$)

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Neutron Energy (MeV)
U_{235} Fission Neutron Energy Spectrum

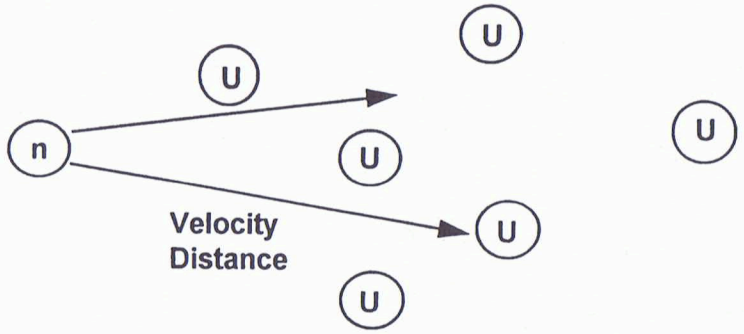


(Reference, Lamarsh, 1966)

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"A Shake"



- **Fission mean free path - how long before it clobbers an atom like URANIUM**
- **Average velocity - how fast it is going**

- $\tau = \dfrac{\textit{fission mean free path}}{\textit{average velocity of neutron}}$

These values are derived experimentally and are related to the fission cross section and velocity of the neutron.

- $\tau = 10^{-8}$ **Seconds or 1 shake**
  (real fast like the shake of a lamb's tail)

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We Care About Neutrons

- An efficient way to fission U^{235} or Pu^{239} is with neutrons.
- The fission of one atom of U^{235} or Pu^{239} releases approximately 200 MeV.
- To create an explosion by fission, a bunch of neutrons are required.
- The more neutrons--the more fission, i.e., We Care About Neutrons!
- Remember that each fission gives off integral numbers of neutrons--about 2-4, but over a bunch of fissions, we measure an average (i.e., 2.54 etc.) and this varies with input neutron energy.

  υ = average number of neutrons

- The whole idea of sustaining the fission process is to get these fission neutrons to go fission more U^{235} or Pu^{239}.
  - If all the neutrons escape without fissioning anything, then the reaction fizzles! (The population becomes extinct.)
  - If at least one of the 2 to 4 neutrons fission something every generation, then we have a steady state condition--a reactor.
  - If most of the neutrons fission another atom etc., etc., we have a run-away condition--a nuclear explosion.

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We Care About the Neutrons that Escape

- We call the escapees "lost neutrons," and the abbreviation is *l* (the letter after k).
- So the number of neutrons available for population growth is the average number per fission (u), i.e., 2.54 minus the lost ones.
- Someone called this k.
- Therefore: k = u - *l*
  - for every neutron causing fission in one generation k will cause it in the next generation.

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We Care About the Multiplication

- Now let's look at a bunch of fissions and bunch of neutrons.
- If we start with some number of neutrons (one or more), let that number equal n.

n = number of neutrons at beginning of a generation

- Remember, k= number of neutrons available for Round 2...
- And k times n equals number of neutrons at the next generation.
- Don't forget we've used up the original neutrons (n) in the first fission process..
- The gain of neutrons is thus:

$$n \bullet k - n$$

(number of neutrons we started with)•(average number in a fission of Round 2 (etc.)) minus the ones we used up in the previous round.

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Determine Growth Rate

- We still care about neutrons, but we really care about the rate (speed) that they are produced.
- The rate is the $\frac{\text{change in the number of neutrons}}{\text{change in time}}$
- Mathematically this is represented

$$\frac{Dn}{Dt} \longrightarrow \frac{dn}{dt}$$

- To get the rate change, we divide the actual gain in neutrons by time (t)

$$\frac{nk - n}{t}$$

- Therefore $\frac{dn}{dt} = \frac{nk - n}{t}$

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Apply Basic Calculus

- $\frac{dn}{dt} = \frac{nk-n}{\tau} = \frac{n(k-1)}{\tau}$

- *Let* α *"alpha"* $= \frac{k-1}{\tau}$ *substitution gives*

- $\frac{dn}{dt} = n\alpha$; *Rearrange (cross multiply and divide)*

- $\frac{dn}{n} = \alpha\, dt$ *Integrate from zero neutrons* (N_o) *to N neutrons.*

- $N = N_o\, e^{\alpha t}$

  If α *is known, one can calculate the number of neutrons at any time* (t).

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The Energy Released is Proportional to the Number of Fissions

$\alpha \approx \frac{\mu - \iota - 1}{\tau} \approx \frac{3-1-1}{\tau} \approx \frac{1}{\tau}$ 1 gen / shake for 1 MeV neutron

where: μ = ave# Neutrons
ρ = Post Neutons

$N = N_o e^{dt} \cong N_o e^{\frac{t}{\gamma}} = e^g$ where g = Number of generations

The energy released is proportional to the number of fissions
The numer of fissions is proportional to the number of neutrons

1 fission $\cong 7 \times 10^{-21}$ tons of TNT
At g = 48 we would have $\approx$ 9800 lbs.

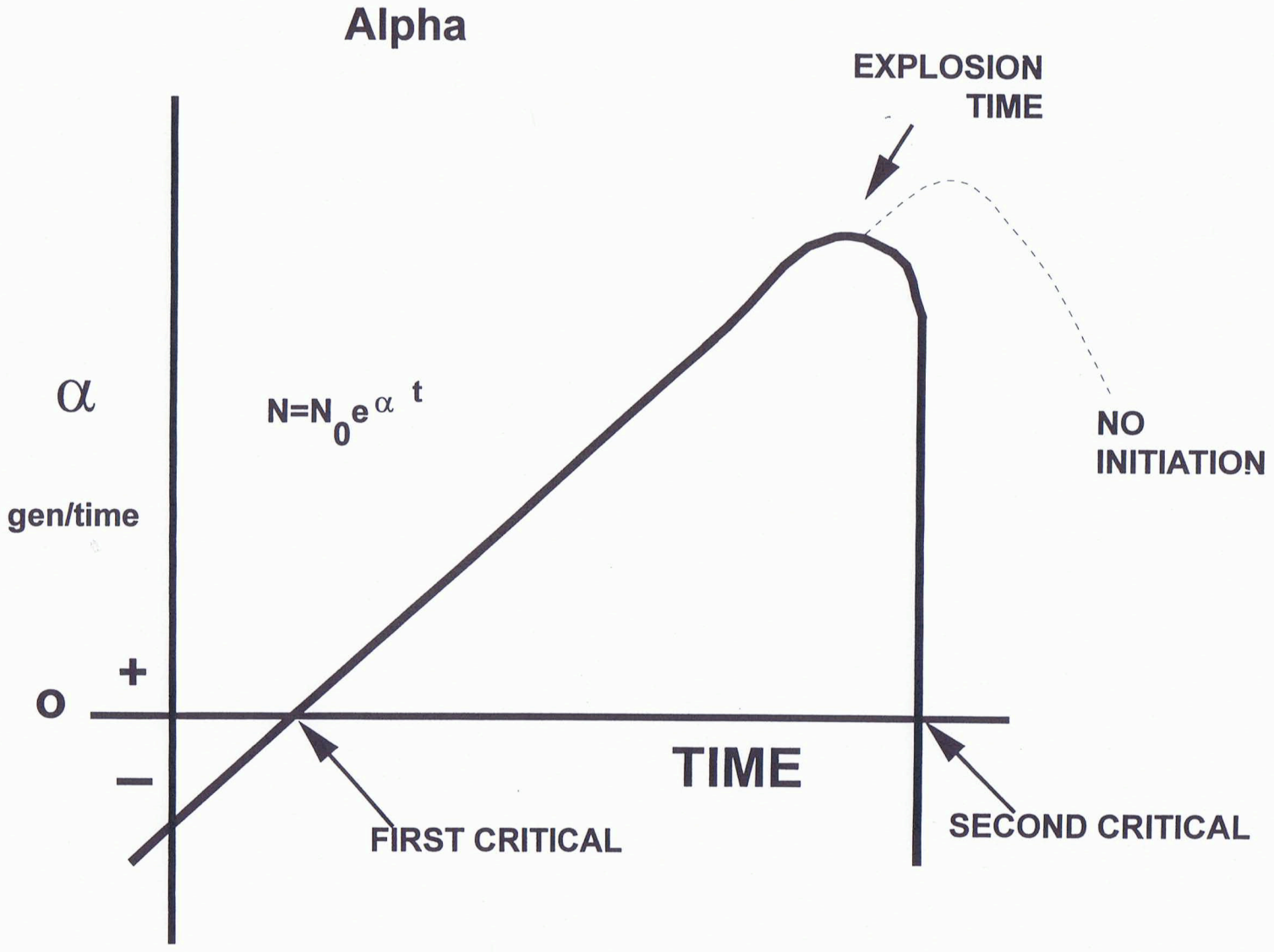
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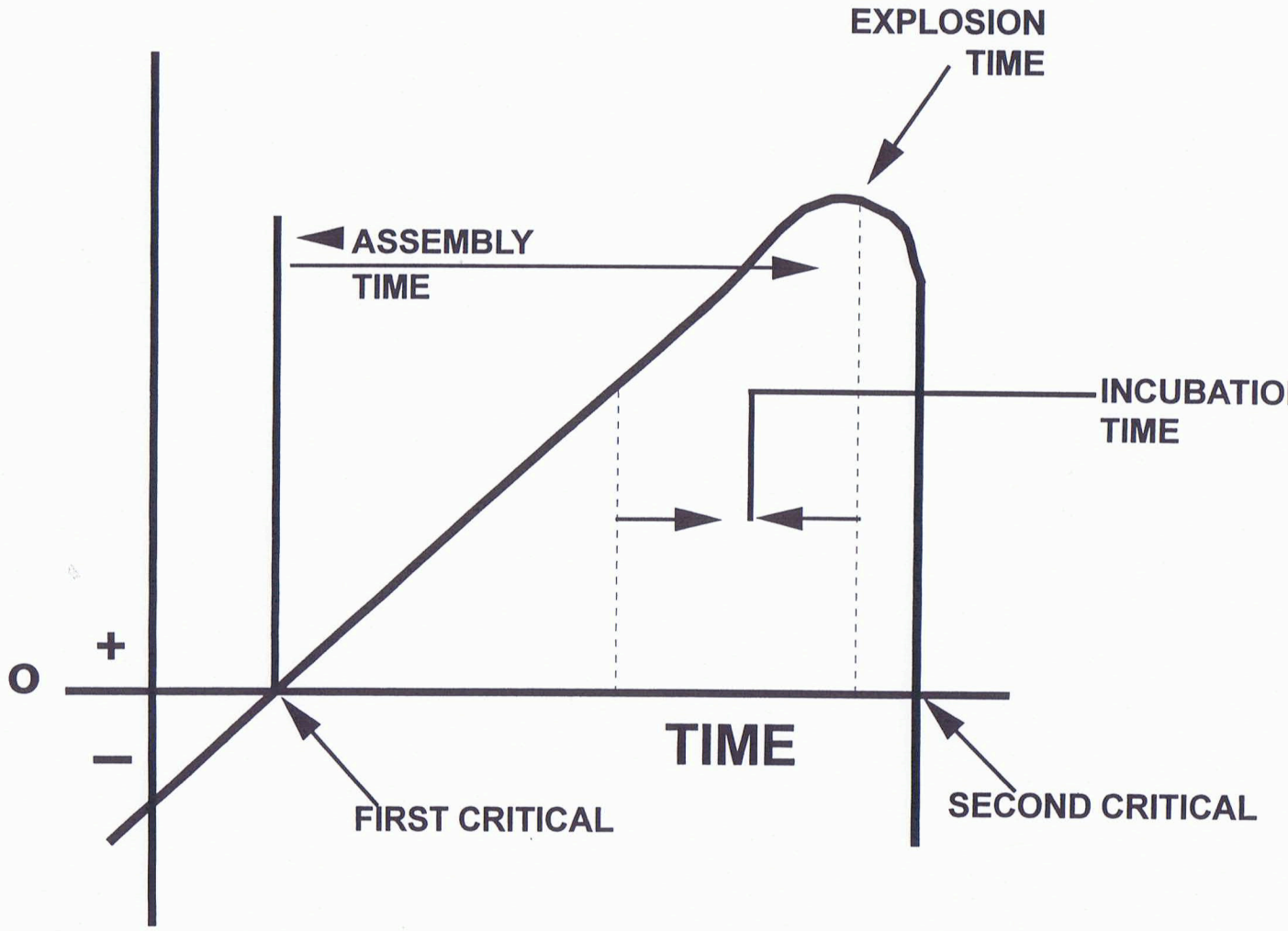
α - Curve



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α - Curve



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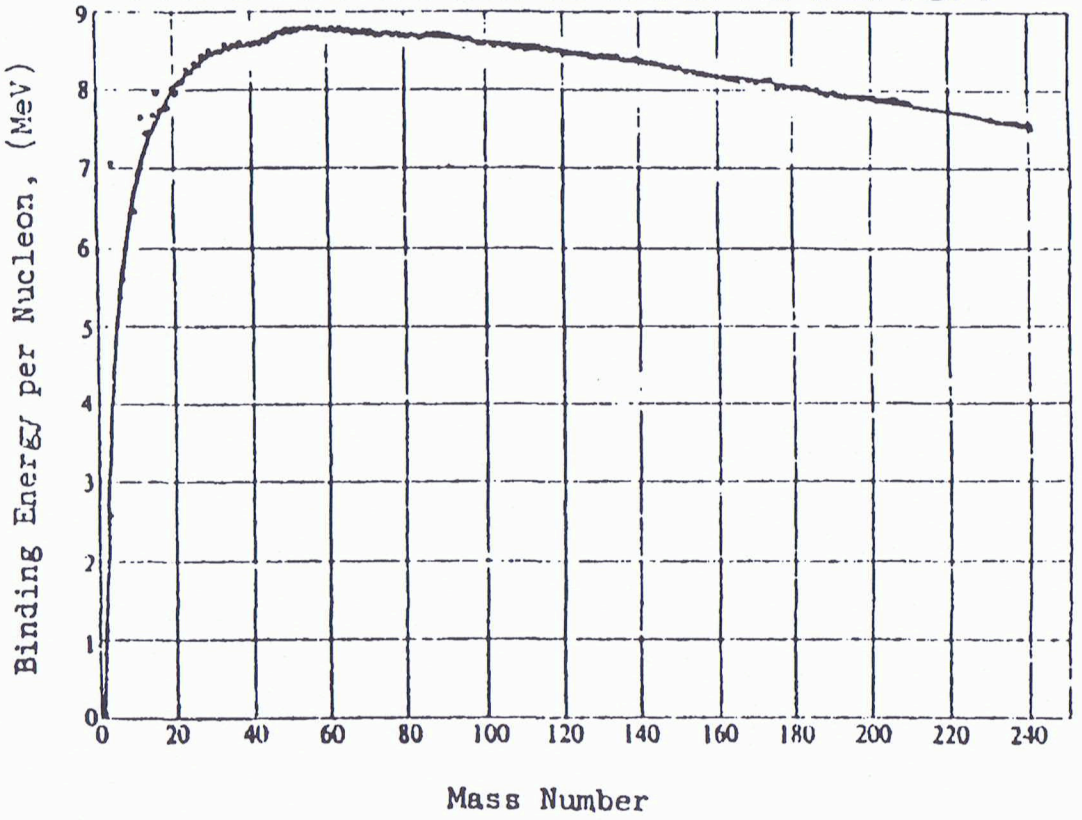
α - Curve

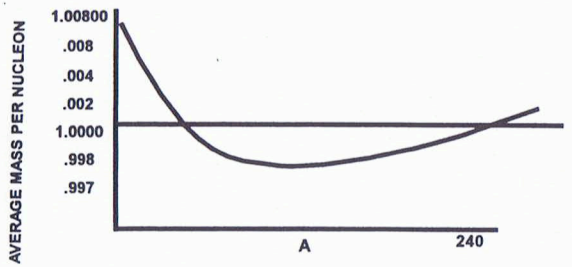
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NUCLEAR BINDING ENERGY



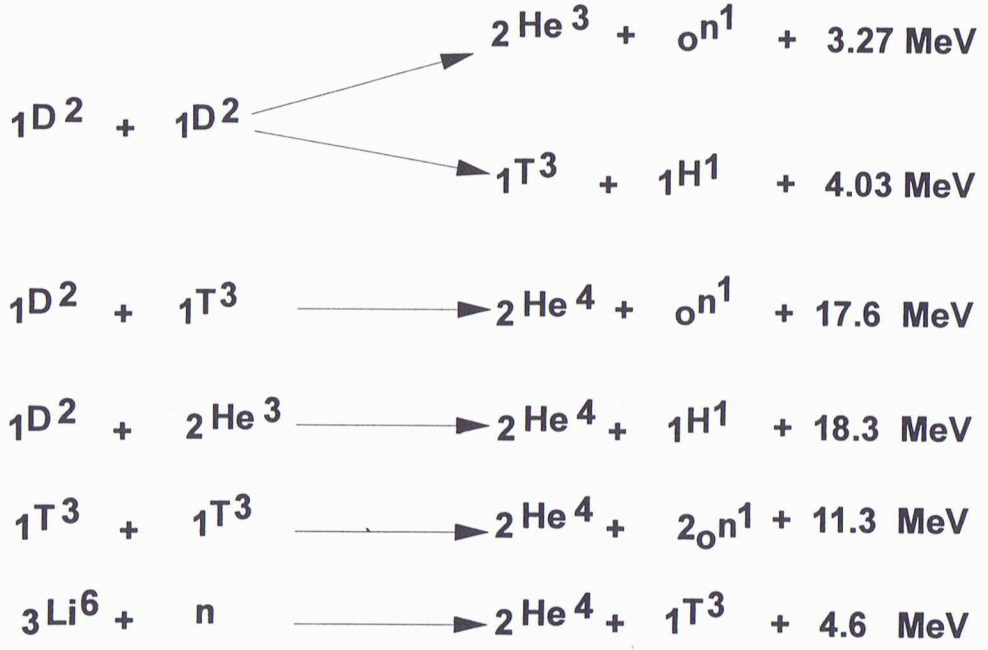


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Potential Fusion Reactions



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Theoretical Fusion Energy in Equal Atom Mixture of Li^6D

1 kg of Li^6 has $\frac{6.025 \times 10^{26}}{6.0151} = 1.00165 \times 10^{26}$ Atoms

1 kg of D has $\frac{6.025 \times 10^{26}}{2.0141} = 2.99141 \times 10^{26}$ Atoms

Hence,

.25084 kg of D has $\left(\frac{2.01410}{6.01512 + 2.0141}\right)\left(2.99141 \times 10^{26}\right) \cong .75038410^{26}$ Atoms

.7491 kg of Li^6 has $\left(\frac{6.01512}{6.01512 + 2.0141}\right)\left(1.00165 \times 10^{26}\right) \cong .750390 \times 10^{26}$ Atoms

$Li^6 + {}_0n^1 \Rightarrow \left(.75039 \times 10^{26}\right)(4.6)\text{MeV} \cong 13.2\text{kT}$

$D + T \left(.75039 \times 10\right)\left(17.6\text{MeV}\right) \cong 50.5\text{kT}$

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TEMPERATURE EXPRESSED IN kT (ENERGY)

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where K is Boltzmann Constant $\left\{ \begin{array}{l} 1.38 \times 10^{-16} \text{ erg/ } ^{\circ}\text{K} \\ 8.62 \times 10^{-8} \text{ keV/ } ^{\circ}\text{K} \end{array} \right.$

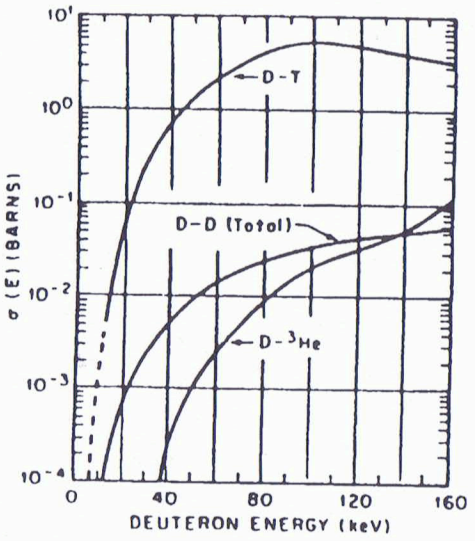
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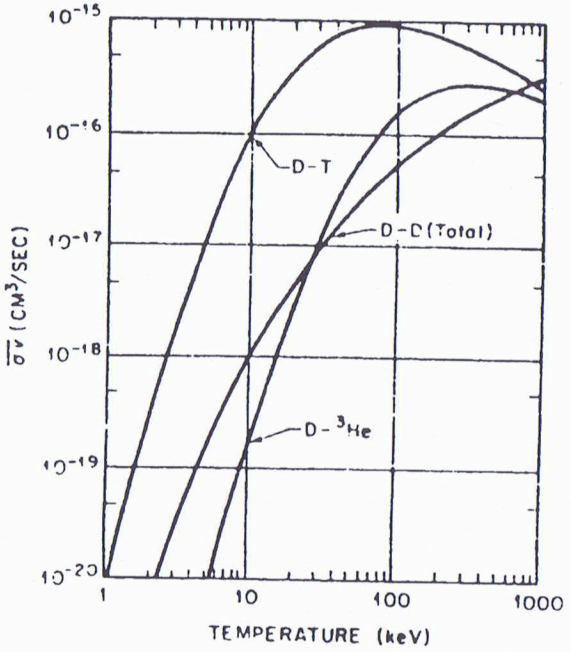
$T \text{ (in keV)} = 8.62 \times 10^{-8} \; T \text{ (in } ^{\circ}\text{Kelvin)}$

Temperature of 1 keV = 1.16×10^{7} degrees Kelvin

Rational for Choice of Fusion Reaction

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FUEL

- ^{6}LiD (95% ^{6}Li, 5% ^{7}Li)

- Tritium

$$^{6}Li + n \rightarrow {}^{4}He + {}^{3}T + 4.6\ McV$$

- Fusion

$$^{3}T + {}^{2}D \rightarrow {}^{4}He + n + 17.6\ McV$$

$$^{2}D + n \rightarrow H + {}^{2}n$$

- Net Reaction

$$^{6}Li + D \rightarrow 2\ {}^{4}He + 22.3\ McV$$

Net Energy = 22.3 McV per Event

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Thermal Nuclear Plasma

AT FUSION TEMPERATURES, WE HAVE A PLASMA OF IONS (NUCLEI AND ELECTRONS).

$$\text{ENERGY} = aT_{(\text{ion})} + bT_{(\text{electron})} + cT^4_{(\text{radiation})}$$

IF PLASMA IS IN THERMODYNAMIC EQUILIBRIUM THE THREE TEMPERATURES ARE EQUAL ➡ AT HIGH TEMPERATURES, RADIATION WILL DOMINATE.

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REFERENCES

AN INTRODUCTION TO NUCLEAR WEAPONS; WASH 1037 REVISED; SRD (n) SIGMA 1 etc.; GLASSSTONE AND REDMAN.

SOURCE BOOK ON ATOMIC ENERGY; GLASSTONE; UNC 3rd EDITION

BASIC NUCLEAR PHYSICS; INTERSERVICE NUCLEAR WEAPONS SCHOOL

DNA PUBLICATIONS – TECHNOLOGY ANALYSIS REPORT

SANDIA, LLL, LANL TECHNOLOGY REPORTS

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION III

- NUCLEAR EFFECTS

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CONVENTIONAL EXPLOSIVE

RELEASE OF ENERGY ARISES FROM THE BREAKING OF CHEMICAL BONDS (ELECTRON BONDS) IN THE HIGH EXPLOSIVE MATERIAL

NUCLEAR EXPLOSIVE

RELEASE OF ENERGY ARISES FROM THE BREAKING OR MAKING OF NUCLEAR BONDS (HADRON-HADRON)

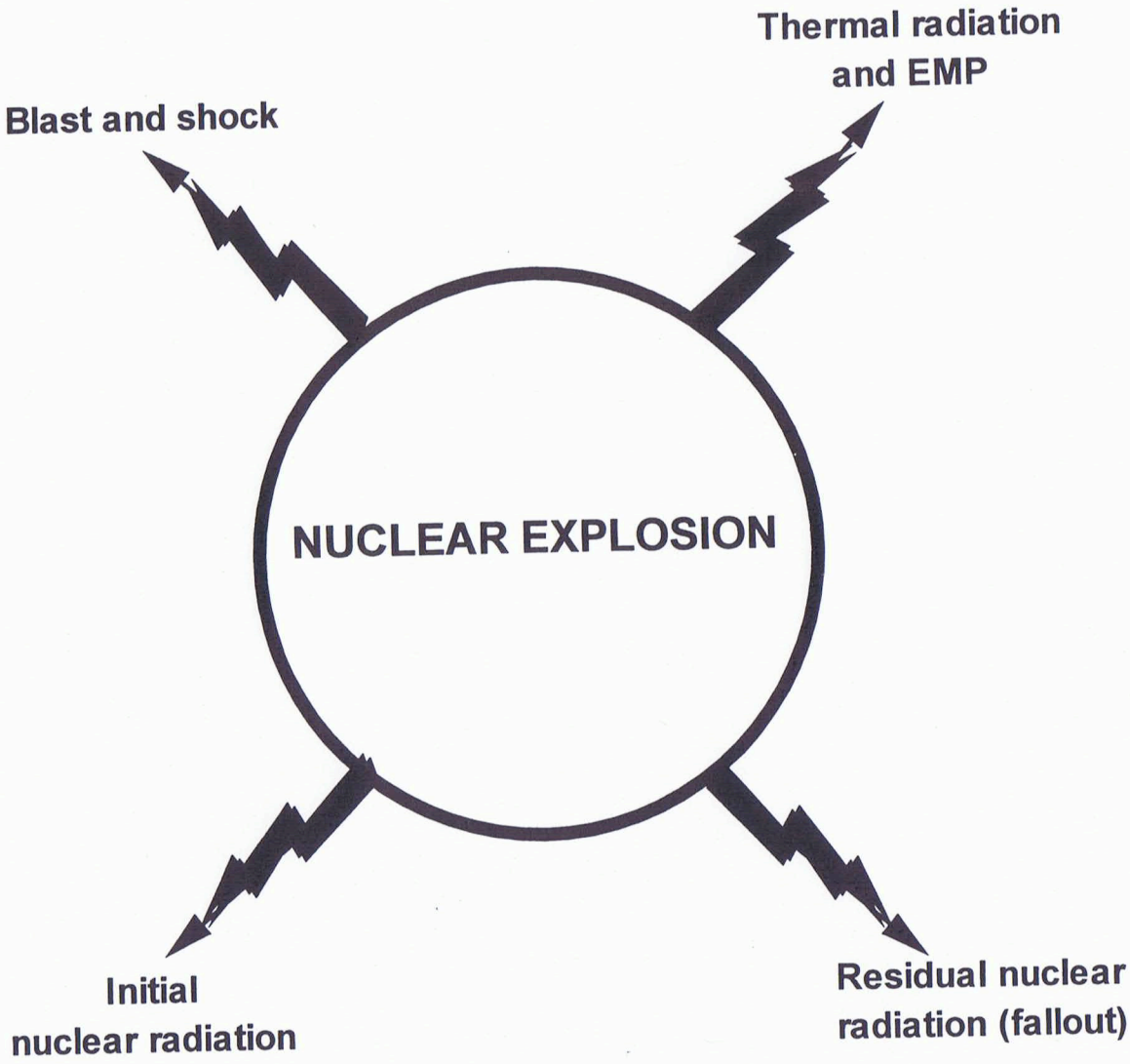
FISSION AND FUSION YIELDS ENERGY RELEASE + PARTICLES

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Effects of a Nuclear Explosion



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Nuclear Effects Generalities

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Subject Generally Divided into 3 areas

- Phenomenology
  - Physics at the weapons source
- Interaction of the nuclear
- Military effects
  - Smashing (over pressure)
  - Turning over (dynamic - winds)
  - Fires (Thermal pulse)
  - Radiation
  - Craters

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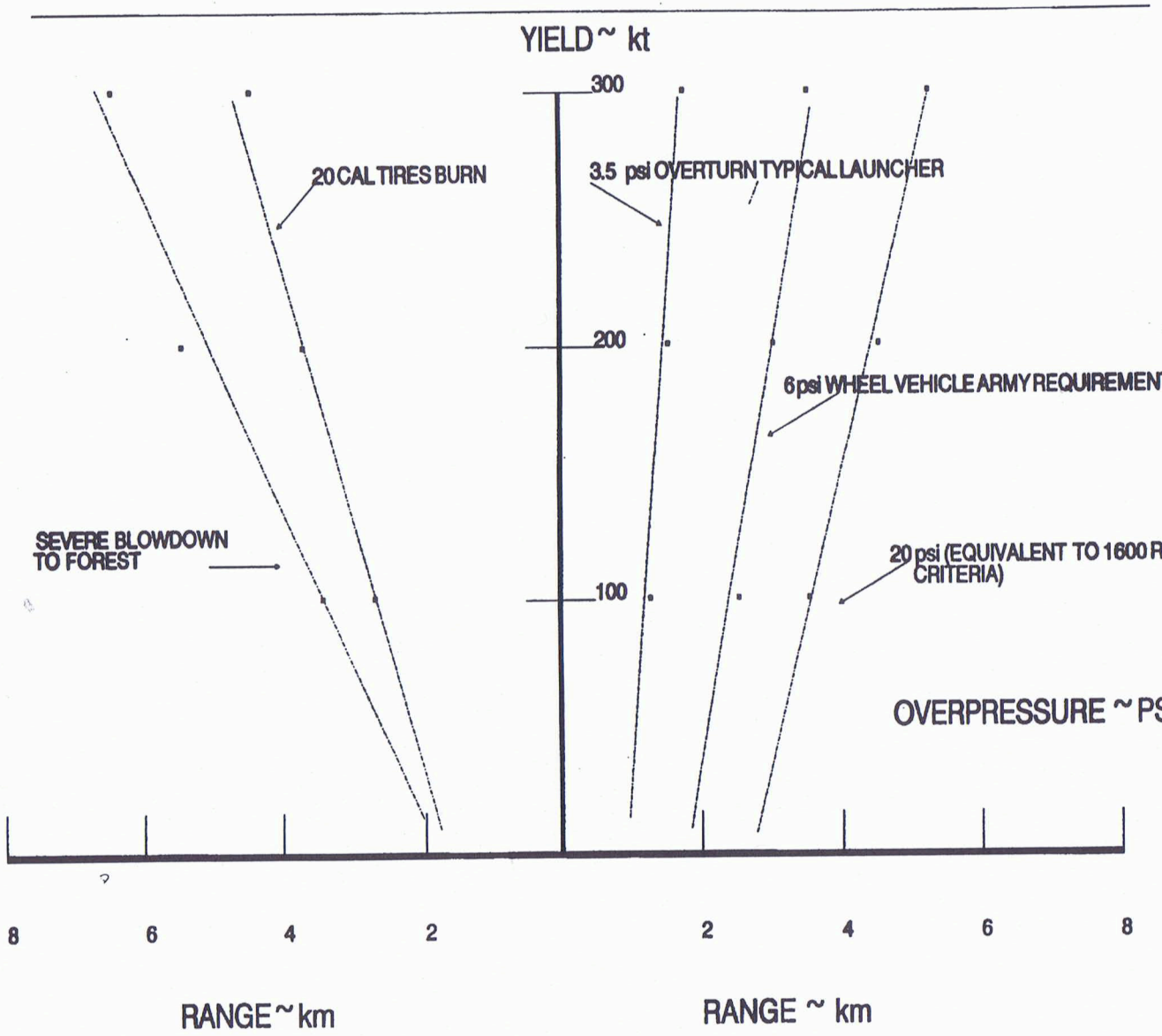
What are Nuclear Effects Calculations Used For?

- Determine how "hard" (radiation, blast, etc.) to make the weapon system (major cost implication)
- Determine the proper yield/accuracy combination
- Placement of weapon system on the battlefield
- Targeting
- Number of nuclear weapons required to achieve an objective
- Safety zones
- Etc.

- Historically, this is an area that has caused much discussion and argument. However, over the years, DNA has developed tools to standardize the methodology and has contributed greatly to the understanding of this area.
  - Textbooks
  - Nomograms/Slide Rules
  - T159 - Programs
  - HP 41 CX - Programs
  - Personal Computer Software

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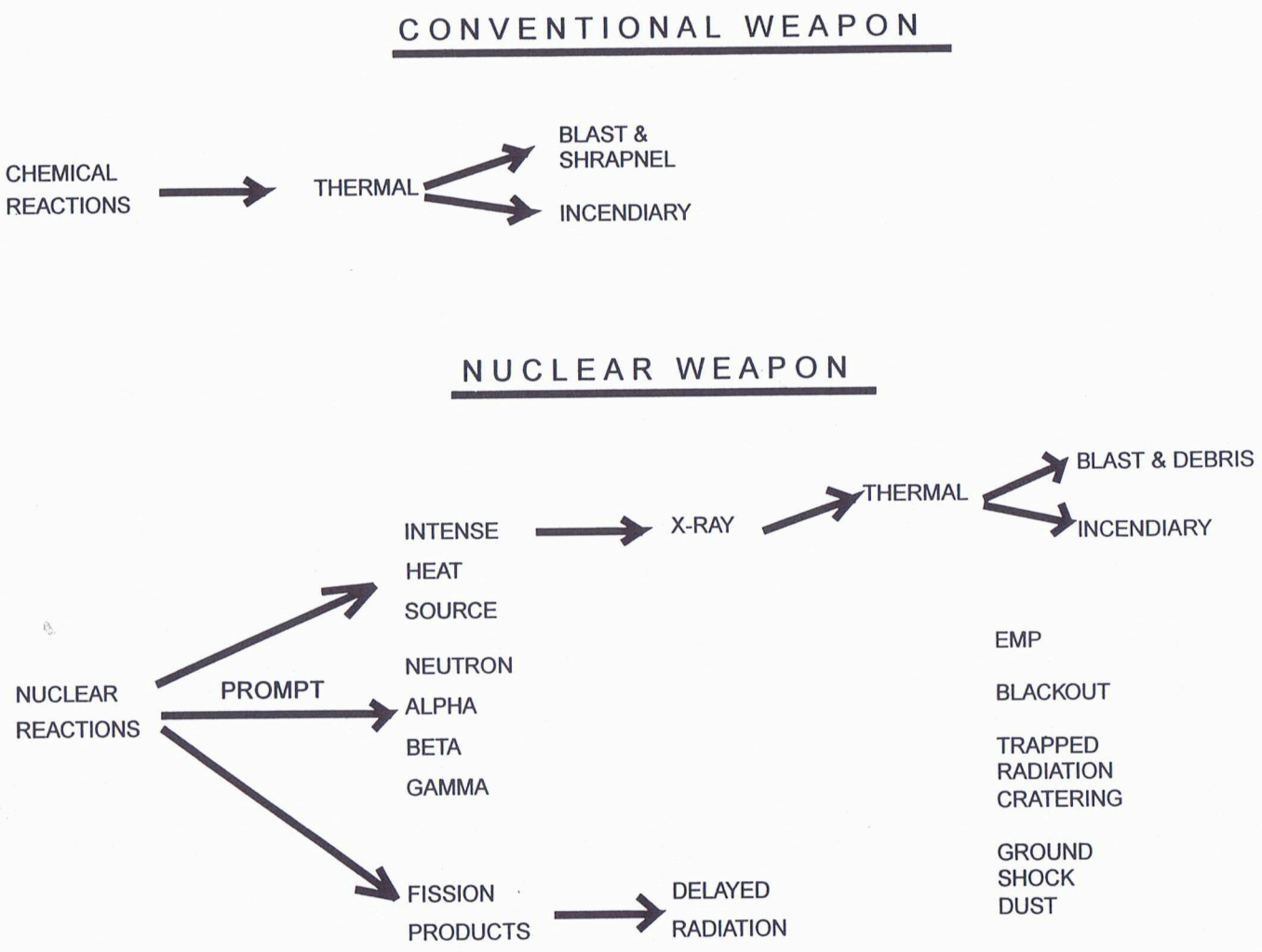
NUCLEAR SEPARATION DISTANCE



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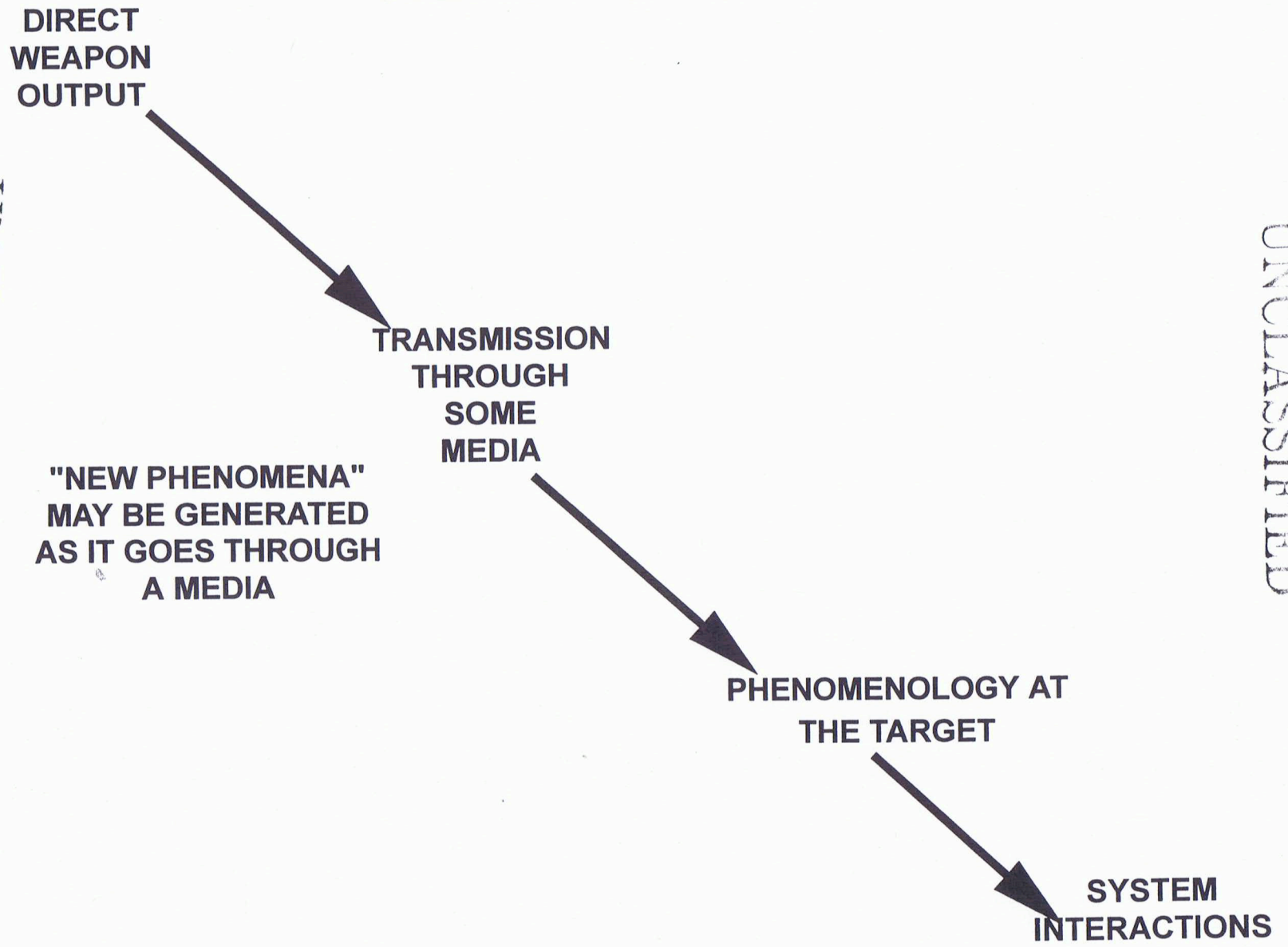
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Nuclear Effects



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THE NUCLEAR PHENOMENOLOGY EXPERIENCED BY A SYSTEM DEPENDS ON:

- YIELD OF WEAPON
- DESIGN OF WEAPON
- WHERE WEAPON WAS DETONATED
- WHERE SYSTEM IS
- FOR SOME EFFECTS, WHAT SYSTEM IS DOING

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NEUTRONS COME DIRECTLY FROM

Fission

N + fissionable material ► two or more fission fragments + neutrons + energy

And

Fusion

D + T ► H_e^4 + neutron + energy

T + T ► H_e^4 + 2 neutrons + energy

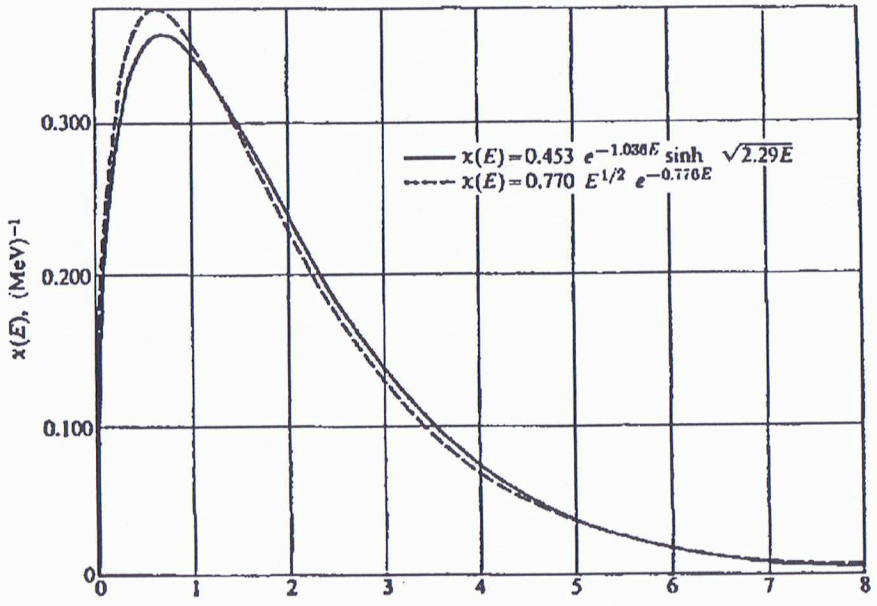
D + D ► H_e^3 + neutron + energy

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Fission Neutron Energy Spectrum



Neutron Energy (MeV)

Reference: Lamarsh, 1966

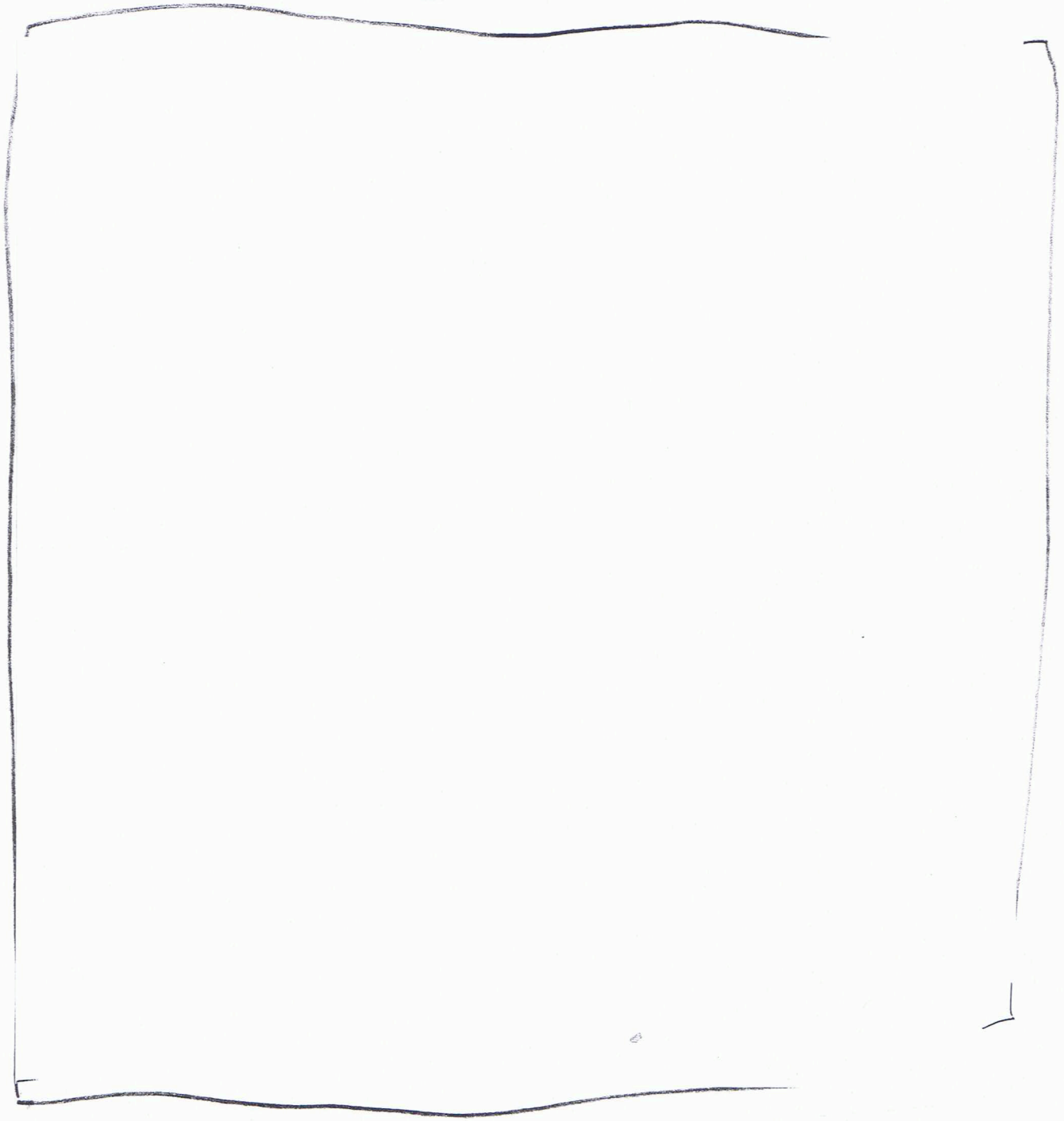
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Neutron Spectra

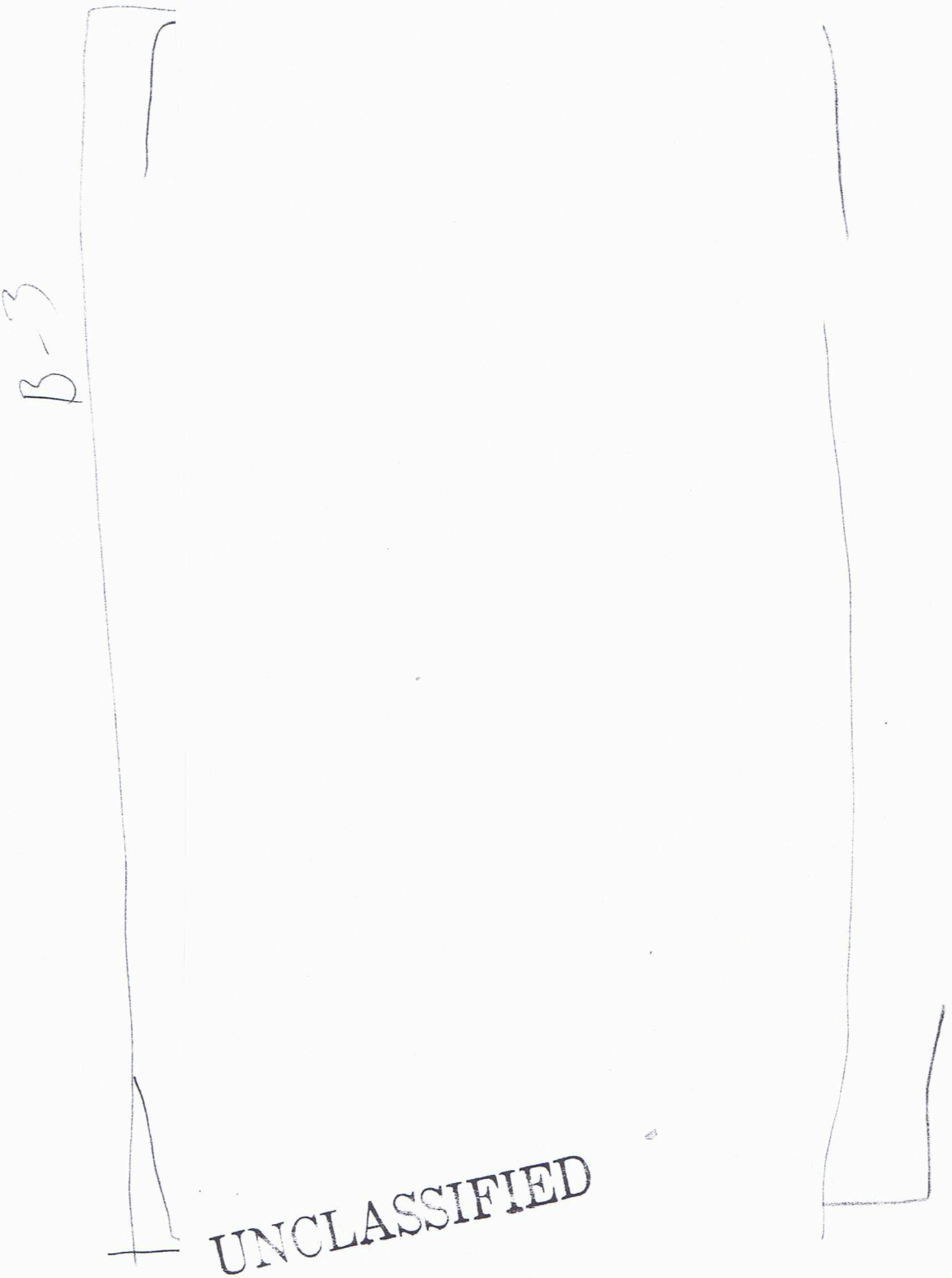
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FREQUENCY (HZ)
WAVE LENGTH (cm)
PHOTON ENERGY (keV)
10^{25}
10^{20}
10^{15}
10^{10}
10^{5}
10^{-15}
10^{-10}
10^{-5}
1
10^{5}
10^{-5}
10^{-10}
γ - rays
X - rays
Far Ultraviolet
Ultraviolet
Visible
Near Infrared
Far Infrared
Microwave
Radio/Radar

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GAMMA RAYS

ELECTROMAGNETIC RADIATION

SOURCE:

- DETONATION FISSIONS

EARLY

- NEUTRON INELASTIC SCATTER IN WEAPON DEBRIS
- NEUTRON INELASTIC SCATTER IN THE AIR AND GROUND

LATER

- CAPTURE OF SLOW NEUTRONS BY NITROGEN
- FISSION PRODUCT DECAY

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BLAST AND THERMAL

IT'S HOT, HOT,----
SO IT RADIATES HEAT

THERE'S HIGH, HIGH, HIGH PRESSURE----
SO IT TRANSMITS A PRESSURE PULSE

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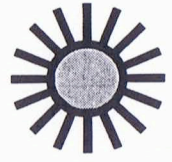
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SEQUENCE OF EVENTS AFTER A NUCLEAR DETONATION IN THE ATMOSPHERE

1. ONCE UPON A TIME THERE WAS A NUCLEAR WEAPON--NOW THERE'S THIS 10 MILLION PLUS DEGREE BLOB OF VAPORIZED MATERIAL OCCUPYING ROUGHLY THE SAME VOLUME (78% OF ENERGY IS IN X-RAY).



2. THIS VOLUME RADIATES ELECTROMAGNETIC ENERGY IN THE X-RAY SPECTRUM.



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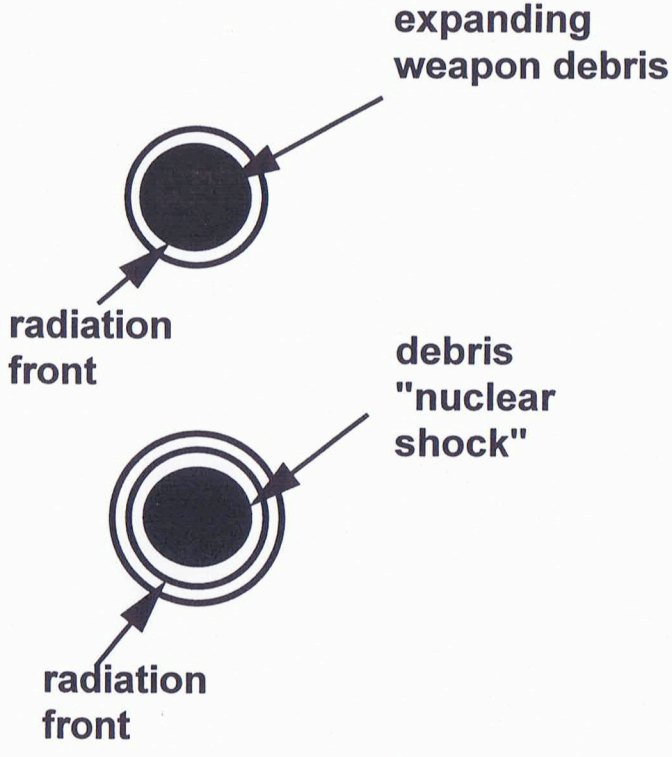
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3. THE MEAN FREEPATH OF "X-RAYS" IS .3 cm AT SEALEVEL. THE SURROUNDING LAYER OF AIR IS SUPERHEATED. INITIAL X-RAY FIREBALL



4. THIS ABSORPTION AND RERADIATING PROCESS RESULTS IN A RAPIDLY EXPANDING RADIATION FIREBALL. RADIATION GROWTH PHASE.

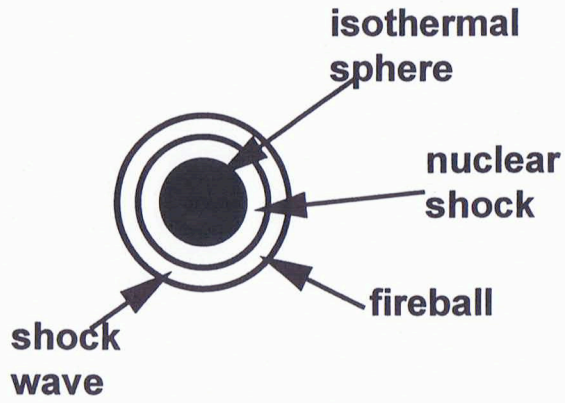
5. THE WEAPON DEBRIS SNOWPLOWS AIR AND A "NUCLEAR SHOCK" IS FORMED. RADIATION FIREBALL CONTINUES TO GROW, BUT GROWTH SLOWS BECAUSE COOLING REDUCES MFP.



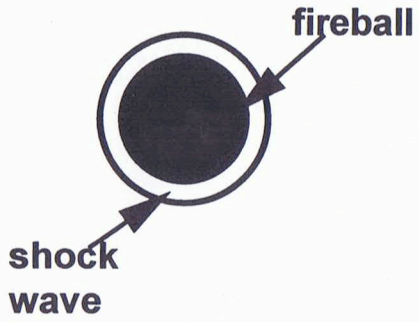
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6. SHOCKWAVE ASSOCIATED WITH THE FRONT BECOMES DOMINANT. NUCLEAR SHOCK STARTS TO "CATCH-UP." HYDRODYNAMIC SEPARATION



7. NUCLEAR SHOCK CATCHES UP, BUT REINFORCED SHOCKWAVE COOLS TO 3,000 DEGREES CELSIUS AND STARTS TO BECOME TRANSPARENT. SHOCK BREAKAWAY.



8. NO FURTHER INTERACTION BETWEEN EXPANDING SHOCKWAVE AND FIREBALL.



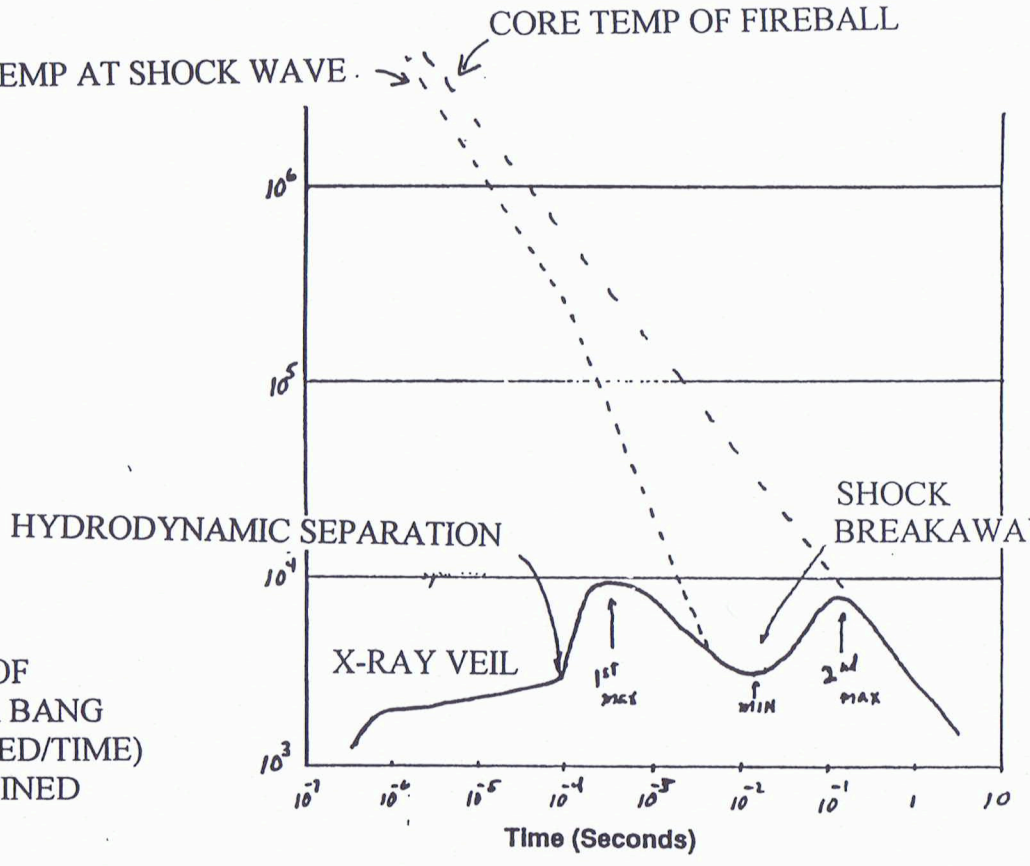
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THERMAL Observed Thermal Pulse



USE: FROM A KNOWLEDGE OF SHOCK BREAKAWAY AND A BANG METER (DISTANCE TRAVELED/TIME) THE YIELD CAN BE DETERMINED

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BLAST



$R_2 > R_1$

OVERPRESSURE $\Delta P = P - P_o$

DYNAMIC (GUST) $P_d = 1/2\ MV^2$

TIME DEPENDENCE

$P_d > \Delta P$ (ΔP>100 PSI)

$P_d < \Delta P$ (ΔP<100 PSI)

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AWAY FROM SOURCE AIRBLAST

SCALABLE PHENOMENA — SACH'S SCALING $\left[\frac{D_1}{D_0}\right] = \left[\frac{W_1}{W_0}\right]^{1/3}$

BASIS IS COMPLETE DATA FOR 1 CASE EX: 1 kT STANDARD

FOR ALTITUDES OTHER THAN SEA LEVEL $\left[\frac{D_1}{D_0}\right] = \left[\frac{W_1}{W_0}\right]^{1/3} \left[\frac{P_0}{P}\right]^{1/3}$

OTHER IMPORTANT ASPECTS:

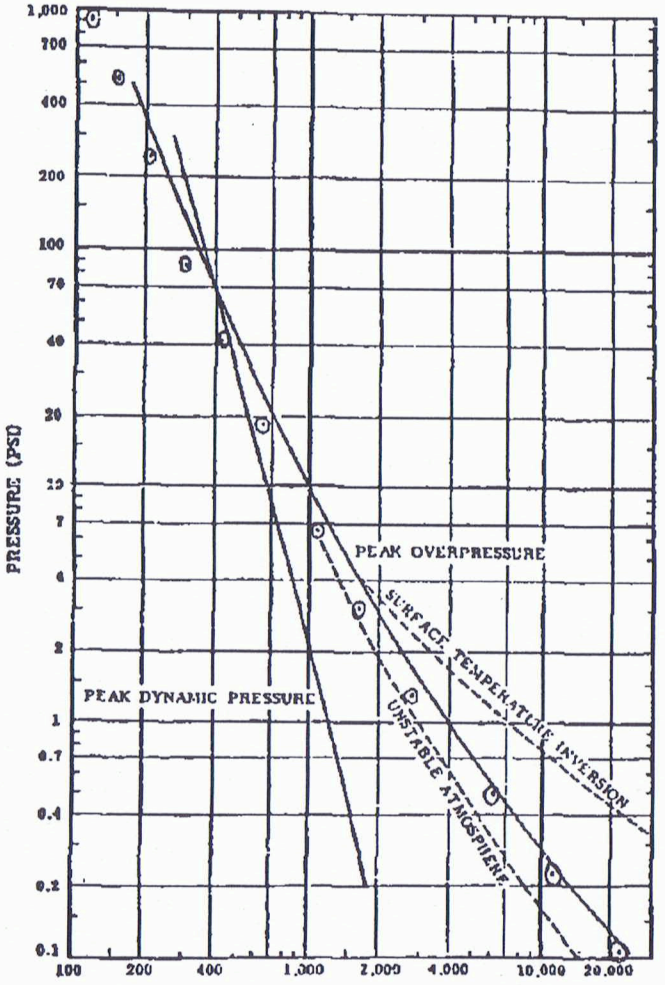
- MACHSTEM AND TRIPLE POINT PATH
- OPTIMAL HOB FOR MAXIMIZING OVERPRESSURE
- PRECURSOR

WILL BE COVERED LATER AND IN THE EFFECTS MOVIE

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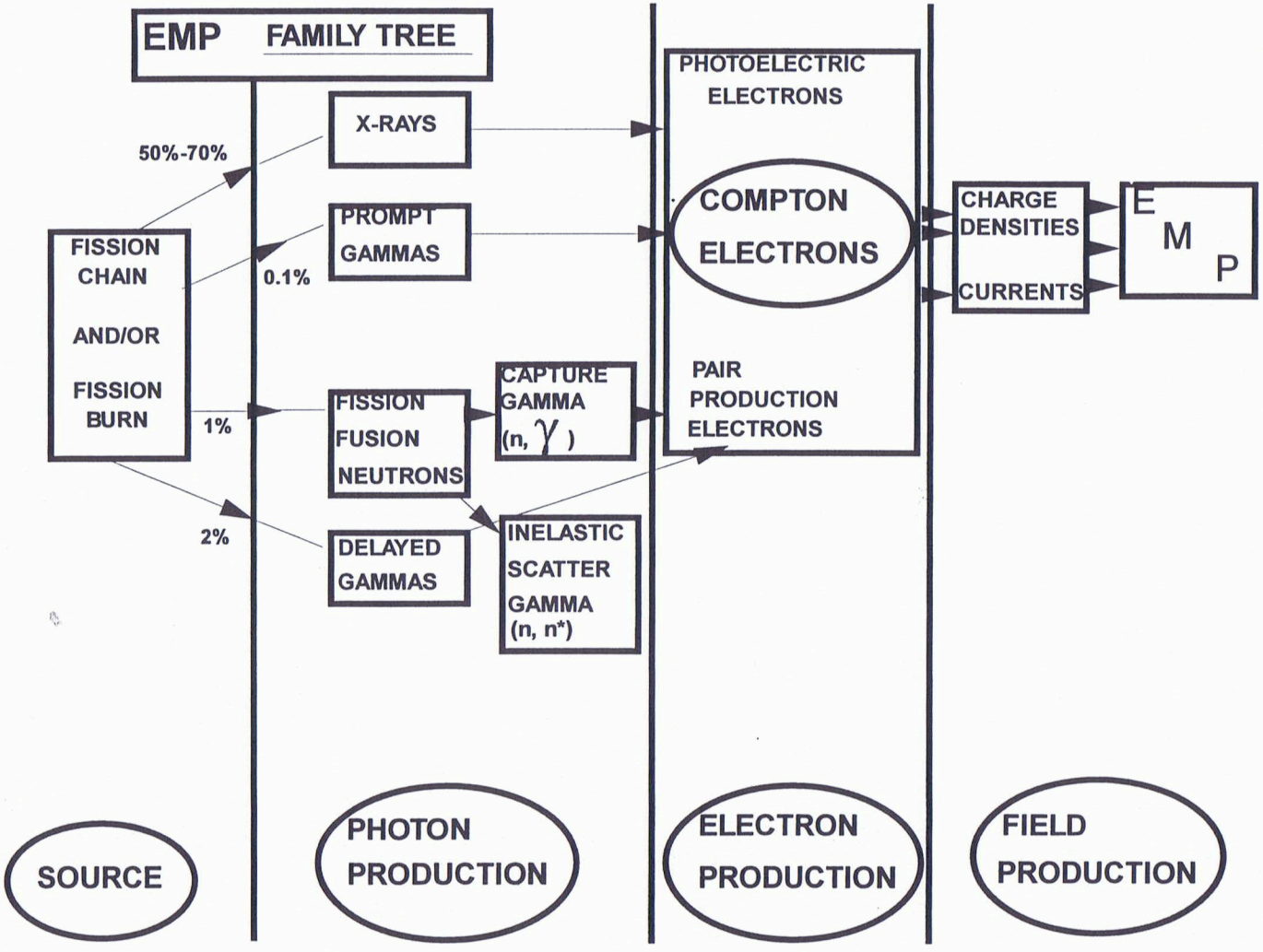
⊙ = Data from AFWL - TR 73-75



Distance from Ground Zero (feet)
1 Kiloton Standard (from Glasstone)

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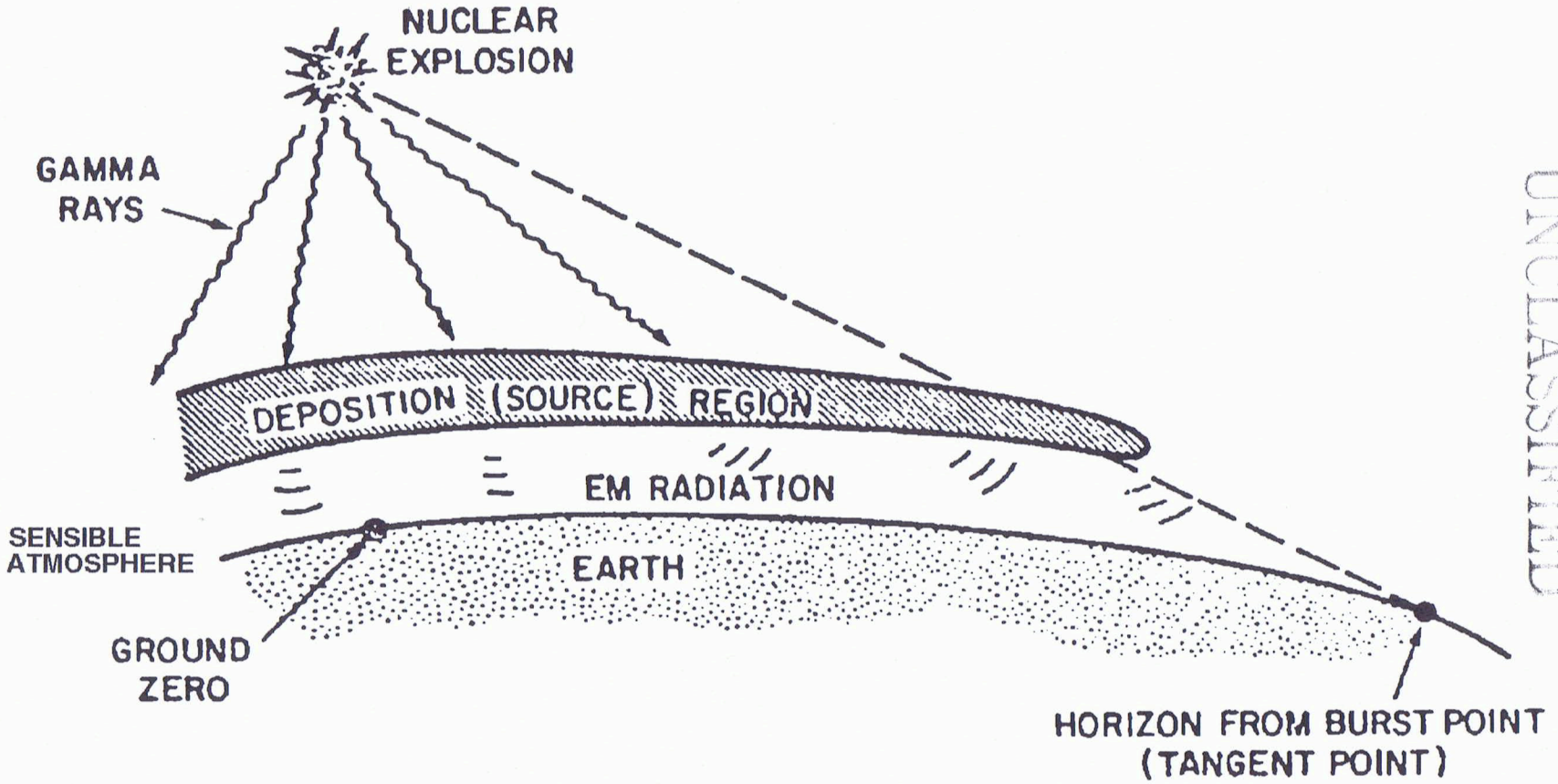
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Bottom Line: electron moves in assymetric field

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High Altitude EMP



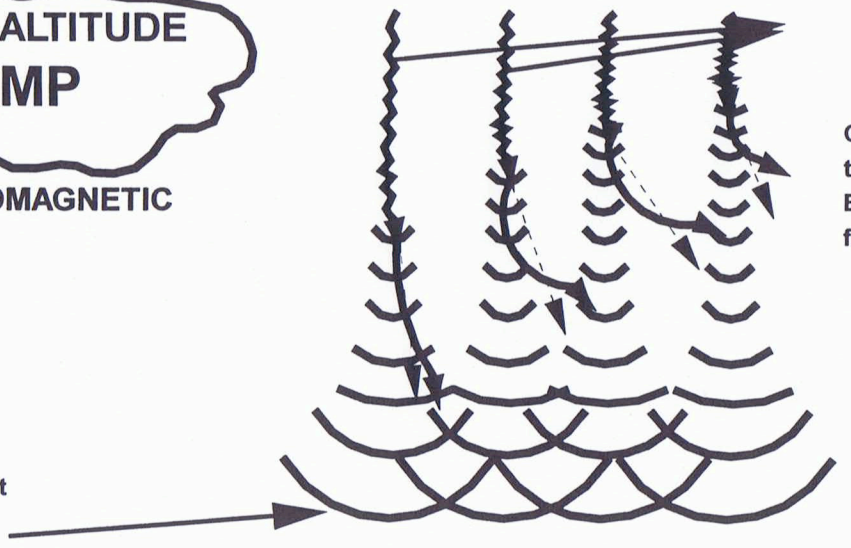
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HIGH ALTITUDE EMP

ELECTROMAGNETIC PULSE



KEY Points

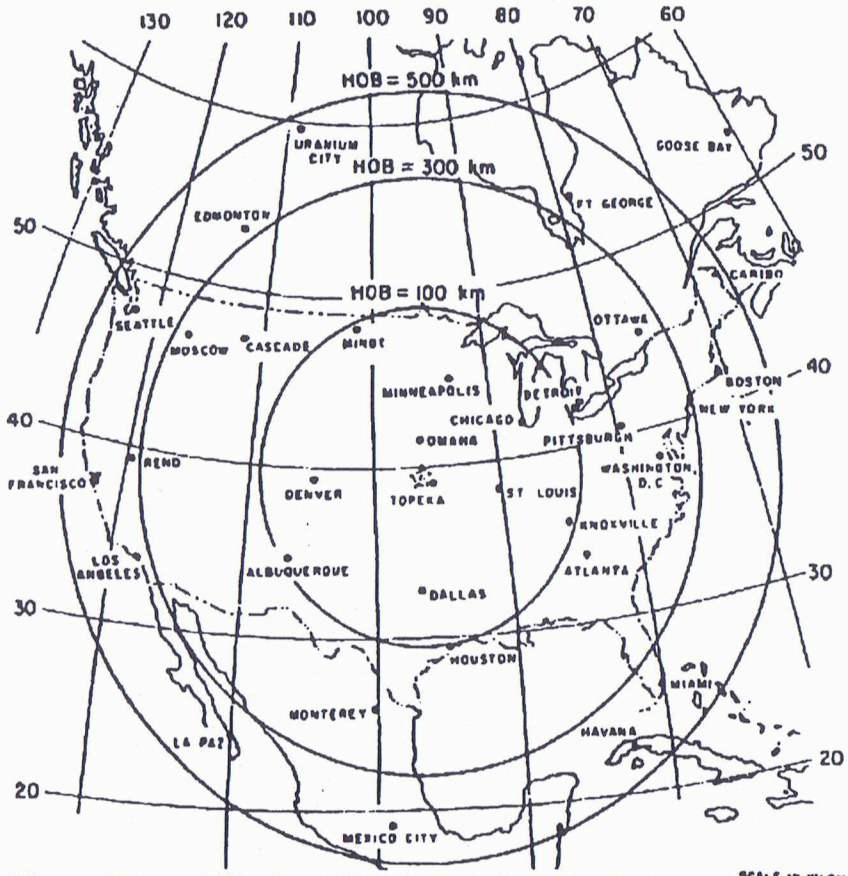
1. Each γ gives a downward traveling compton electron.
2. The electrons are turned by the earth's magnetic field.
3. The relativistic electrons radiate energy downward.
4. The γ 's and EMP radiation travel at the same speed.
   This leads to constructive interference of radiation from all electrons.

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EMP PULSE

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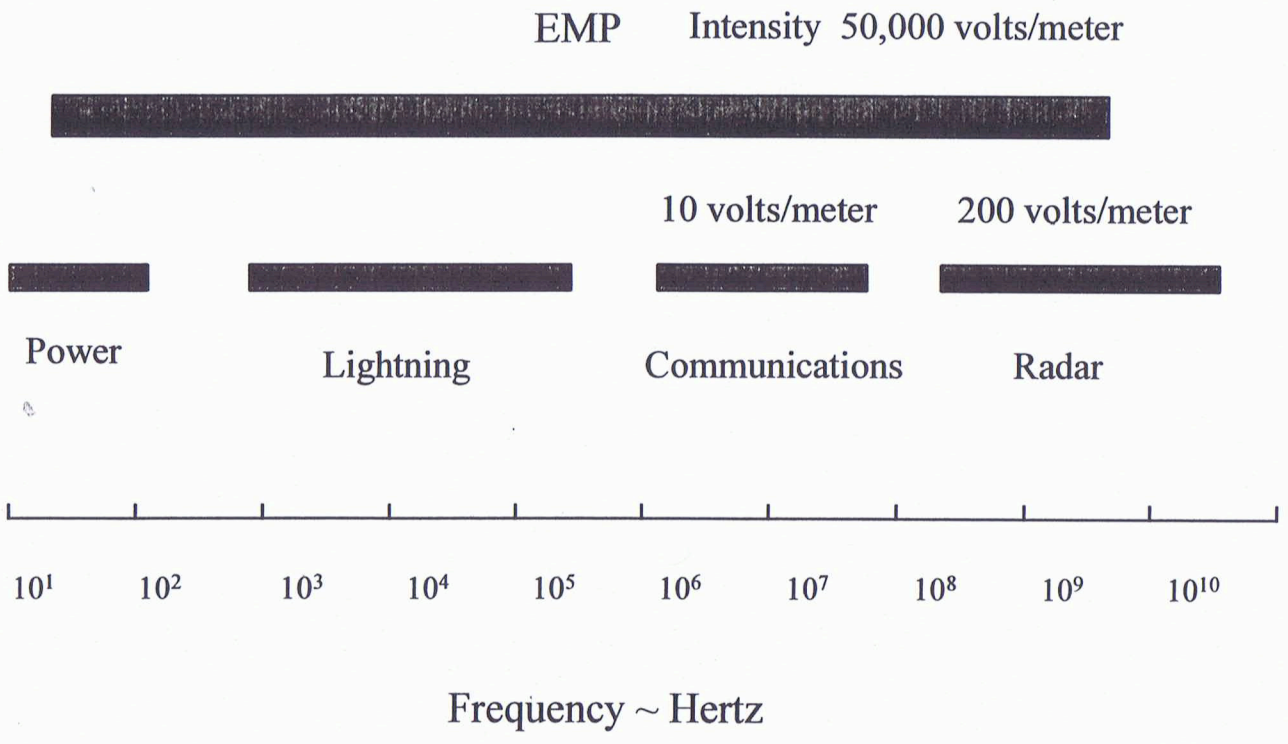


Ground Coverage for Bursts of 100, 300, and 500 km (about 62, 186, and 310 miles) for a Large Yield Burst Above the Geographical Center of the (counterminous) United States

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Frequency Spectrum Comparison

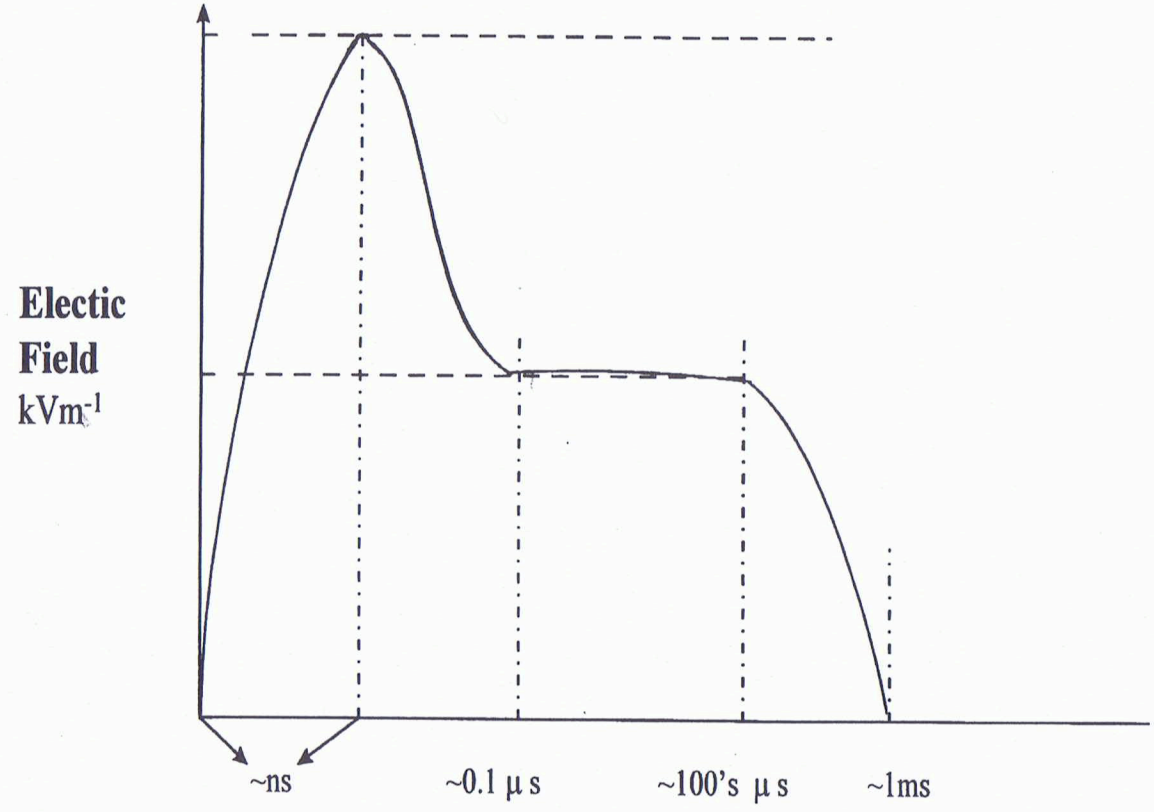
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Representative EMP Pulse

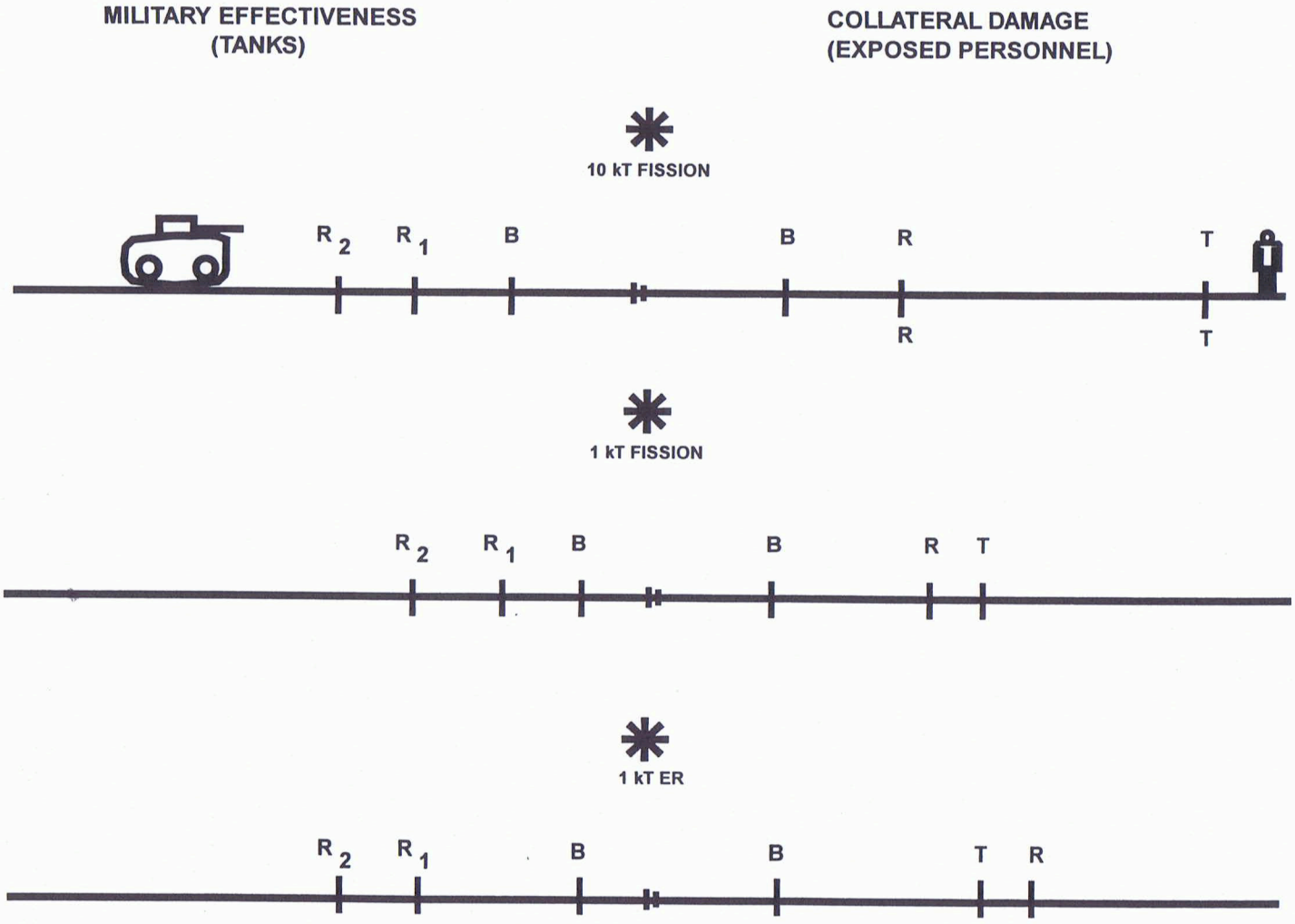
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1 MT DETONATIONS AT VARIOUS HOB's (CO-Altitude)

	N 10^{12} n/cm^2	N 10^{15} n/cm^2	γ 10^{8} rad/sec	γ 10^{13} rad/sec	X-ray 20 cal/cm^2	X-ray 130 cal/cm^2	Thermal 4 cal/cm^2	Thermal 80 cal/cm^2	Over 2 psi	Over 10 psi	Over 3000 psi
Exoatmospheric	157	5.6	760	2.4	56.8	22.2	-----	-----	-----	-----	-----
100,000 ft	12.5	5.5	190	2.3	10.4	6.0	98	22	8.5	4.6	.7
1,800 ft	6.2	2.5	9.0	1.3	-----	-----	49	19	29.5	10.8	.8
Surface	5.6	2.3	8.5	1.3	-----	-----	40.4	12.1	25	10	1.1

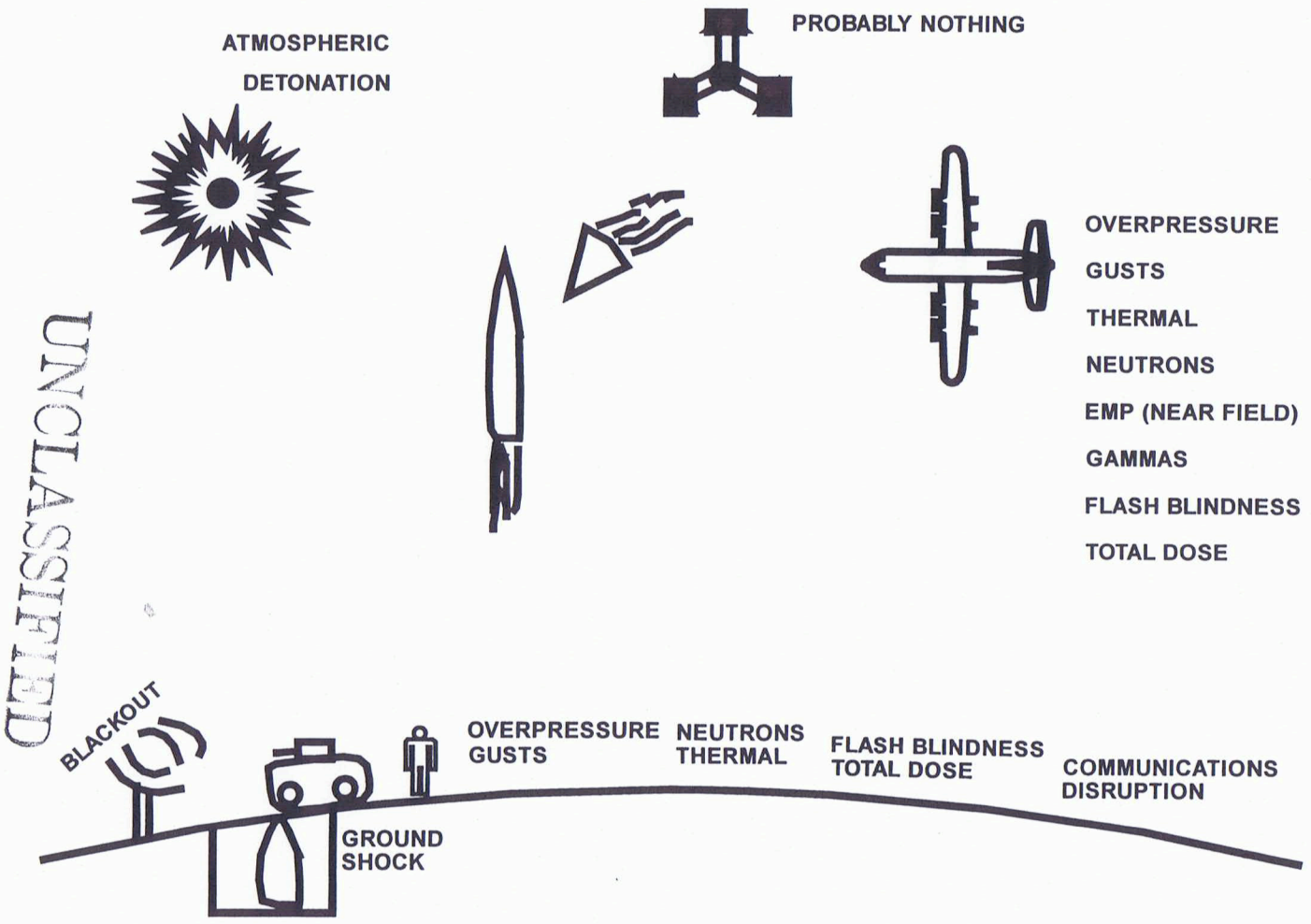
Distances to Effect Levels in kilo-feet

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Useful Rules-of-Thumb for Prompt Effects

- Emergency Risk
  - Thermal -- 3 cal/cm2
  - Blast -- 4 psi
- Casualty from Blast
  - Exposed personnel -- 18 psi
  - Severe Tank Damage -- 49 psi
- Radiation Dose
  - Casualty -- 8,000 rads
  - Emergency Risk -- 150 rads

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Radiation Dose Immediate Casualty -- 8,000 rads

Range	Yield	Adjustment factor
~0.5 km	~1 KT fission	~100m range for every factor 2 in yield
~1 km	~ 1 KT enhanced Radiation	~100m range for every factor 2 in yield
~1 km	~ 25 KT typical Fission	~100m range for every factor 2 in yield

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Radiation Dose-Prompt Effects

Casualty	8,000 rads	~0.5 km	1 KT fission
Casualty	8,000 rads	~ 1 •km	1 KT ER
Casualty	8,000 rads	~ 1 km	25 KT fission
Emergency Risk	150 rads	~1.5 km	1 KT ER
Emergency Risk	150 rads	~1.5 km	25 KT fission

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SOME EFFECTS LEVELS OF INTEREST

PEOPLE

THERMAL	2-5 CAL/CM2
OVERPRESSURE	>7 PSI
RADIATION	>100 RADS

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Nuclear Targeting

- Through intelligence data, the targets have a vulnerability number associated with it that allows the DoD to assign a weapon VN number.
- Vulnerability Number (VN)

  XXPA XXQA

  First 2 digits are related to the amount of pressure:
  - P = over pressure (smash)
  - Q = dynamic pressure (winds)
  - A = adjustment for yield (tables geared to 20 kT)
- A typical VN:

  Airfield = 12 P0 ~ 10 psi

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REFERENCES

•THE EFFECTS OF NUCLEAR WEAPONS 3RD EDITION, GLASSTONE AND DOLAN, 1977, UNC

•CAPABILITIES OF NUCLEAR WEAPONS, DNA EM-1 PARTS I & II, SRD RS-3141 8798

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION IV

- HIGH EXPLOSIVES
- DETONATORS

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PRIMARY

- **EASILY IGNITED WITH QUICK TRANSITION TO DETONATION**
- **SMALL QUANTITY REQUIRED**

SECONDARY

- **INSENSITIVITY**
- **HIGH ENERGY DENSITY**

PHYSICAL SEPARATION - TETRYL

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Material[a]	Chemical name	Other designations	Color
*BTF	Benzotris-[1,2,5] oxadiazole-[4,4,7]-trioxide	Benzotrifuroxan, hexanitrosobenzene	Buff
*DATB	1,3-Diamino-2,4,6-trinitrobenzene		Yellow
*DIPAM	3,3-Diamino-2,2',4,4',6,6'-hexanitrobiphenyl	Hexanitrodiphenyl-amine hexite, dipicrylamine	—
*DNPA	2,2-Dinitropropyl acrylate		Off-white
*EDNP	Ethyl-4,4-dinitropentanoate		Yellow
*FEFO	Bis(2-fluoro-2,2-dinitroethyl)-formal		Straw
**HMX	1,3,5,7-Tetranitro-1,3,5,7-tetraazacyclooctane	Cyclotetramethylene tetranitramine, octogen	White
*HNAB	2,2',4,4',6,6'-Hexanitroazo-benzene		Orange
*HNS	2,2',4,4',6,6'-Hexanitrostilbene		Yellow
**NC (12% N)[b]	Partially nitrated cellulose	Nitrocellulose (lacquer grade), cellulose trinitrate, piroksilin	White
*NC (13,35% N, min)[b]	Partially nitrated cellulose	Nitrocellulose, guncotton	White
*NG	1,2,3-Propanetriol trinitrate	Nitroglycerin	Clear
*NM	Nitromethane		Clear
*NQ	Nitroguanidine	Aminomethaneamidine	White
**PETN	Pentaerythritol tetranitrate	Penthrite, TEN	White
**RDX	1,3,5-Trinitro-1,3,5-triaza-cyclohexane, hexahydro-1,3,5-trinitro-s-triazine	Cyclotrimethylene trinitramine, hexogen cyclonite,Gh	White
*TACOT	Tetranitro-1,2,5,6-tetraazadi-benzocyclooctatetrene	Tetranitrodibenzo-1,3a,4,6a-tetraazapentalene	Red-orange
**TATB	1,3,5-Triamino-2,4,6-trinitro benzene		Bright yellow
**Tetryl	2,4,6-Trinitrophenylmethyl-nitramine		Yellow
**TNM	Tetranitromethane		Clear
**TNT	2,4,6-Trinitrotoluene	Trotyl,T,tol	buff to brown

**Denotes it has been used in nuclear weapons

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Cast explosives: names and formulations.

Explosive[a]	Formulation (wt%)[b] TNT	RDX	Other ingredients	
Baratol	24		$Ba(NO_3)_2$	76
Boracitol	40		Boric Acid	60
*Comp B, Grade A[c]	36	63	Wax	1
Comp B-3	40	60		
*Cyclotol[d]	25	75		
H-6	30	45	Wax	5
			Al	20
			$CaCl_2$	0.5
*Octol	25		HMX	75
*Pentolite[d]	50		PETN	50
Tritonal	80		Al	20

[a]Properties of materials marked with asterisks are summarized in data sheets (Section IV).

[b]The weight percent values given in the table are nominal and subject to some variation.

[c]Comp B, Grade A is formulated as a 60/40 RDX/TNT mixture, but high-quality castings usually are higher in RDX content due to the removal of a TNT-rich section at the top of the casting.

[d]There are several cyclotols and pentolites. The most common cyclotol is RDX/TNT 75/25. The most common pentolite is PETN/TNT 50/50.

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Plastic-bonded explosives: Names and formulations.

Explosive[a]	Other ingredients	Formulation Ingredient	wt%	Color
*LX-04-1	PBHV-85/15	HMX	85	Yellow
		Viton A	15	
*LX-07-2	RX-04-BA	HMX	90	Orange
		Viton A	10	
*LX-09-0	RX-09-CB	HMX	93	Purple
		pDNPA	4.6	
		FEFO	2.4	
LX-09-1		HMX	93.3	Purple
		pDNPA	4.4	
		FEFO	2.3	
*LX-10-0	RX-04-DE	HMX	95	Blue-green spots
		Viton A	5	on white
LX-10-1		HMX	94.5	Blue-green spots
		Viton A	4.5	on white
*LX-11-0	RX-04-PI	HMX	80	White
		Viton A	20	
*LX-14-0		HMX	95.5	Violet spots
		Estane 5702-FI	4.5	on white
*PBX-9007	PBX-9007 Type B	RDX	90	White or mottled
		Polystyrene	9.1	gray
		Di(2-ethyl-hexyl)-phthalate	0.5	

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Plastic-bonded explosives: Names and formulations. (cont.)

		Formulation		
		Rosin	0.4	
*PBX-9010		RDX	90	White
		Kel-F	10	
*PBX-9011	X-0008	HMX	90	Off-white
		Estane 5740-X2		
*PBX-9205		RDX	92	White
		Polystyrene	6	
		Di(2-ethyl-hexyl)-phthalate	2	
*PBX-9404	PBX-9404-03	HMX	94	White or blue
		NC (12.0% N)	3	
		Tris (B-chloro-ehtyl)-phosphate	3	
*PBX-9407		RDX	94	White or black
		Exon 461	6	
*PBX-9501		HMX	95	White
		Estane	2.5	
		BDNPA	1.25	
		BDNPF	1.25	
PBX-9502		TATB	.05 Kel F	
LX-17		TATB	.075 Kel F	

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EBW (EXPLODING BRIDGEWIRE) EVOLVED

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REFERENCES

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- AN INTRODUCTION TO NUCLEAR WEAPONS; WASH 1037 REVISED; GLASSTONE, JUNE 1972
- PROPERTIES OF CHEMICAL EXPLOSIVES AND EXPLOSIVE SIMULANTS; LLL JULY 31, 1974, DOBRATZ UCRL - 51319, REV 1
- SENSITIVITY OF INITIATION-SYSTEM DETONATORS: REVIEW OF CURRENT AND ADVANCED TECHNOLOGIES; R. E. SETCHELL; SAND91-1590

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REFERENCES

- AN INTRODUCTION TO NUCLEAR WEAPONS; WASH 1037 REVISED, GLASSTONE, JUNE 1972

- SOURCE BOOK ON ATOMIC ENERGY; GLASSTONE, 3rd EDITION

- NUCLEAR TEST SUMMARY TRINITY — HARDTACK DASA 1220; RS3141/10349

- VARIOUS WEAPON DEVELOPMENT REPORTS

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REFERENCES

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION VII

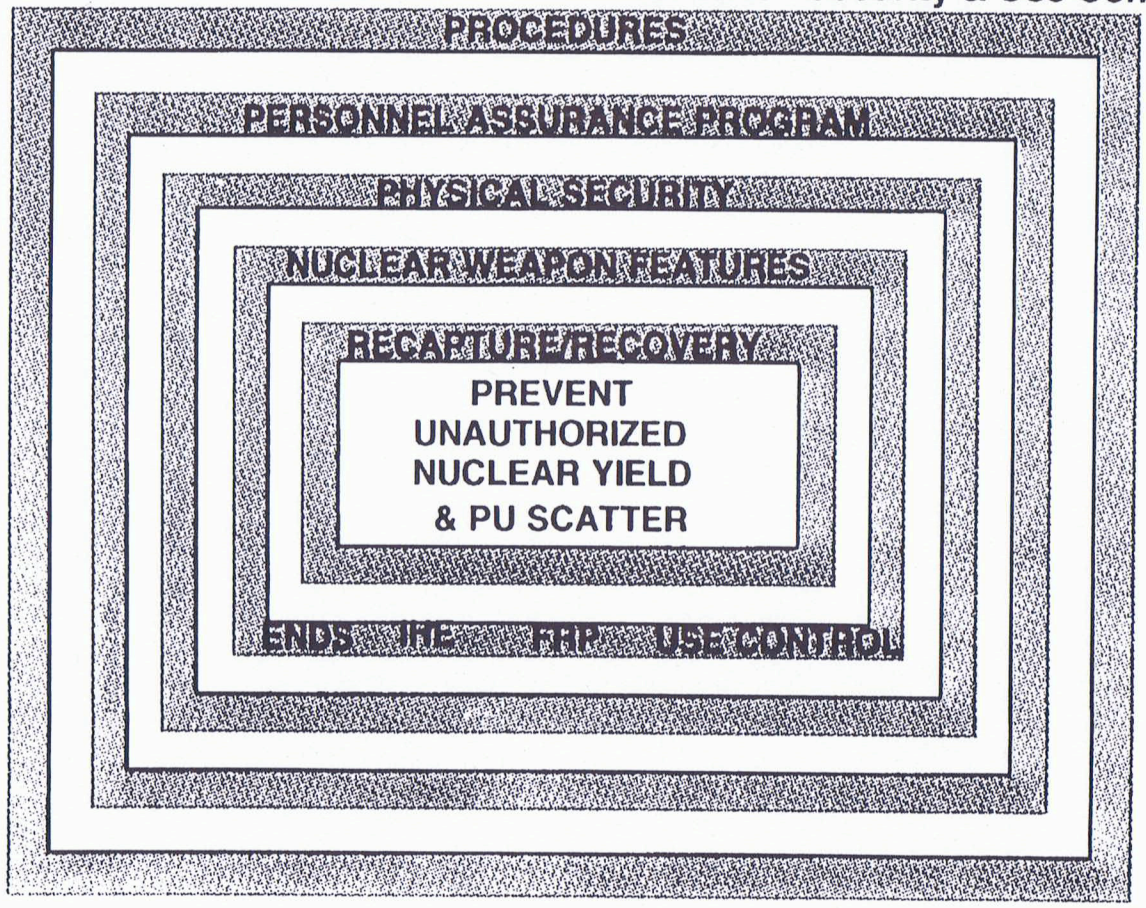
- NUCLEAR DETONATION SAFETY
- NUCLEAR MATERIAL SCATTER

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Surety

PART OF A LAYERED NATIONAL PROGRAM PROTECTING AGAINST UNAUTHORIZED NUCLEAR DETONATION OR PLUTONIUM SCATTER

THE ADVERSARY: → Accidents - Safety
Humans - Security & Use Control



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Nuclear Weapon Surety aims to prevent three consequences

Nuclear yield - release of nuclear energy greater than the energy of four pounds of high explosive

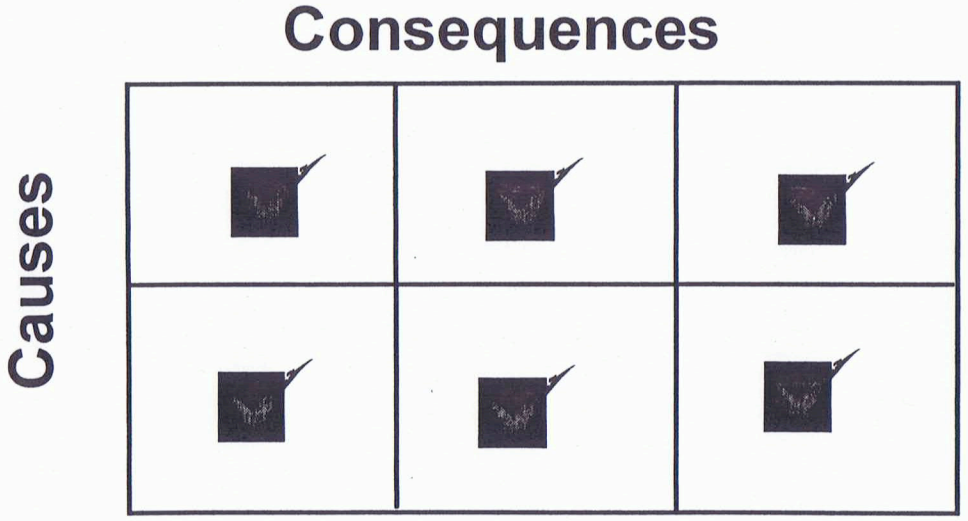
Launch or release - sending a nuclear weapon toward a target

Pu dispersal - release of plutonium outside the weapon

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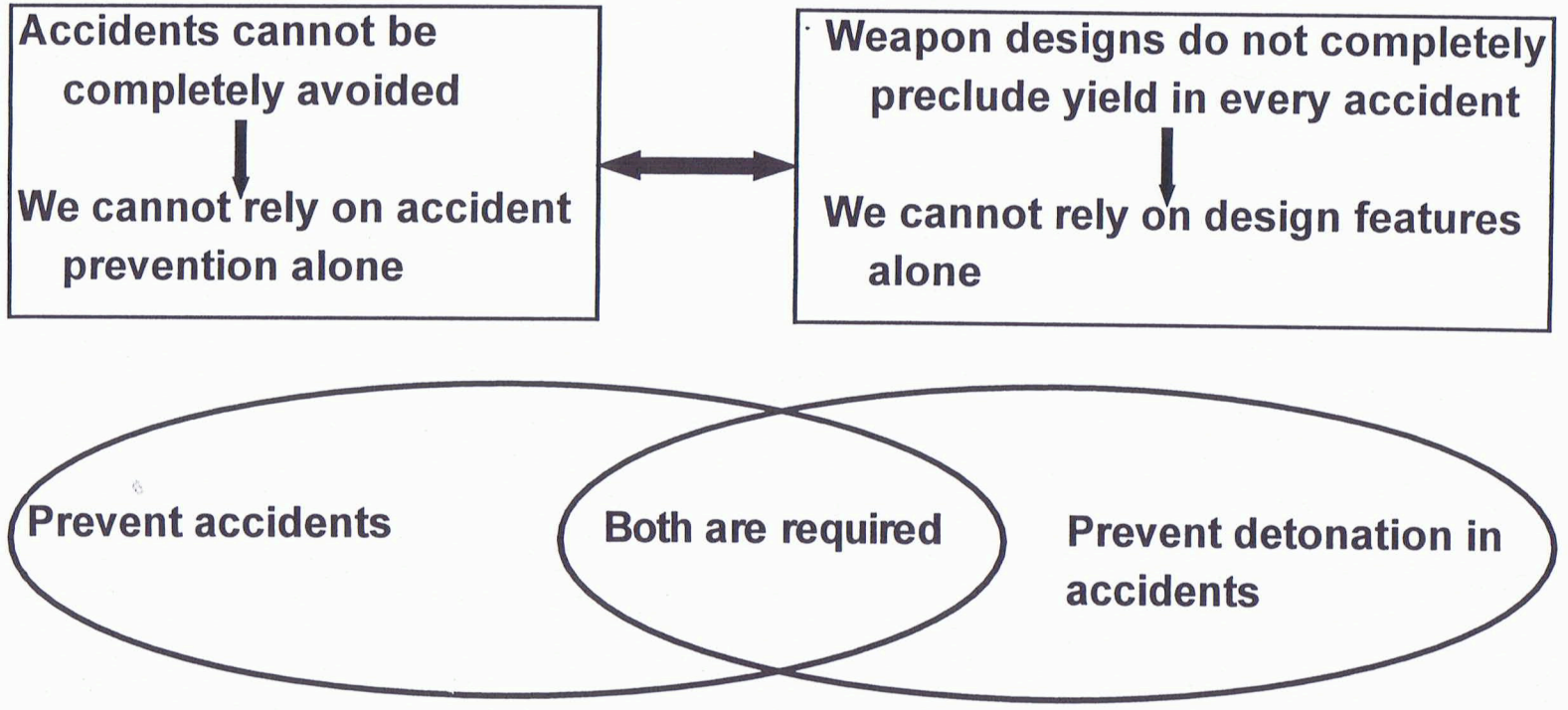
The goal of surety standards

Compliance with nuclear weapon system surety standards should provide assurance against undesired consequences
(nuclear yield, launch, or Pu dispersal)
resulting from any causes
(either intended or unintended).



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The dual approach to nuclear weapons safety



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DOE shares responsibility for safety, security, and control

From the 1983 Memorandum of Understanding between DOE and DoD on Objectives and Responsibilities for Joint Nuclear Weapon Activities

"The obligation of the DoD and the DOE to protect public health and safety provides the basic premise for dual-agency judgment and responsibility for safety, security and control (S ^{2}C) of nuclear weapons. This check-and-balance role shall continue. The DoD and the DOE share the responsibility to:

1) Identify and resolve health and safety problems connected with nuclear weapons. In particular, the DOE has a continuing responsibility to participate with the DoD in the consideration of these health and safety problems for nuclear weapons in DoD custody.

2) Prevent unauthorized use of a nuclear weapon through the use of positive control measure...

3) Determine the adequacy and effectiveness of physical security measures..."

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Department of Defense Directive

3150.2

Replaces DoD 5030.15...February 8, 1984

SAFETY STANDARDS

1. There shall be positive measures to prevent nuclear weapons involved in accidents or incidents, or jettisoned weapons, from producing a nuclear yield.

2. There shall be positive measures to prevent deliberate prearming, arming, launching, firing, or releasing of nuclear weapons, except upon execution of emergency war orders or when directed by competent authority.

3. There shall be positive measures to prevent inadvertent prearming, arming, launching, firing, or releasing of nuclear weapons in all normal and credible abnormal environments.

4. There shall be positive measures to ensure adequate security of nuclear weapons, pursuant to DoD Directive 5210.41.

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DOE Order 5610.10
10/10/90
Nuclear Explosive Safety Standards

a. There shall be positive measures to prevent nuclear explosives involved in accidents or incidents from producing a nuclear yield.

b. There shall be positive measures to prevent deliberate prearming, arming, or firing of a nuclear explosive except when directed by competent authority.

c. There shall be positive measures to prevent the inadvertent prearming, arming, launching, firing, or releasing of a nuclear explosive in all normal and credible abnormal environments.

d. There shall be positive measures to ensure adequate security of nuclear explosives pursuant to the DOE safeguards and security requirements.

e. There shall be positive measures to prevent accidents, inadvertent, or deliberate unauthorized dispersal of plutonium to the environment.

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DOE Nuclear Explosive Surety Standard

All DOE nuclear explosive operations shall meet the the following qualitative surety standards to prevent unintended nuclear detonation, fissile material dispersal from the pit, or loss of control. There shall be positive measures to:

- Minimize the possibility of accidents, inadvertent acts, or authorized activities that could lead to fire, high explosive deflagration, or unintended high explosive detonation;
- Minimize the possibility of fire, high explosive deflagration, or high explosive detonation, given accidents or inadvertent acts;
- Minimize the possibility of deliberate unauthorized acts that could lead to high explosive deflagration or high explosive detonation;
- Ensure adequate security of nuclear explosives;
- Minimize the possibility of or delay unauthorized nuclear detonation.

Reference: DOE Order 452.1, October 4, 1996

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Positive Measures

From DOE Order 5610.10

- Design features, safety rules, procedures, or other controls used individually or collectively to provide nuclear explosive safety.
- Positive measures are intended to assure a safe response in applicable operations and be controllable.
- Examples
  - strong-link switches
  - other safety devices
  - administrative procedures and controls
  - general and specific nuclear explosive safety rules
  - design control of electrical equipment and mechanical tooling physical, electrical, and mechanical restraints incorporated in facilities and transport equipment

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Explanation of normal and abnormal environments

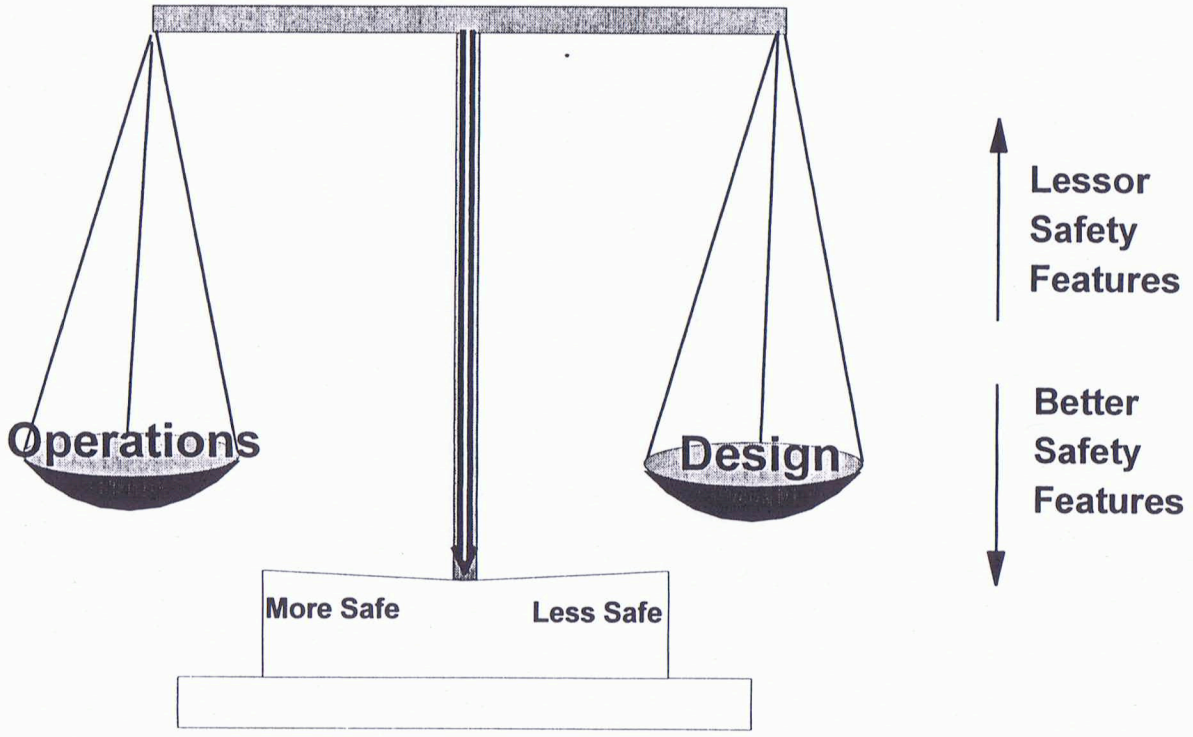
Normal environments (temperature, shock, electrical connections, etc.) are those defined in the weapon or system specifications and intended to be tolerated by the weapon or system. The system is designed to function normally during its entire lifetime if it experiences normal environments.

Abnormal environments are conditions experienced by the weapon or system that are outside the defined normal environments (more extreme temperatures, shocks, voltages, etc.). The weapon or system is not required to function after exposure to an abnormal environment.

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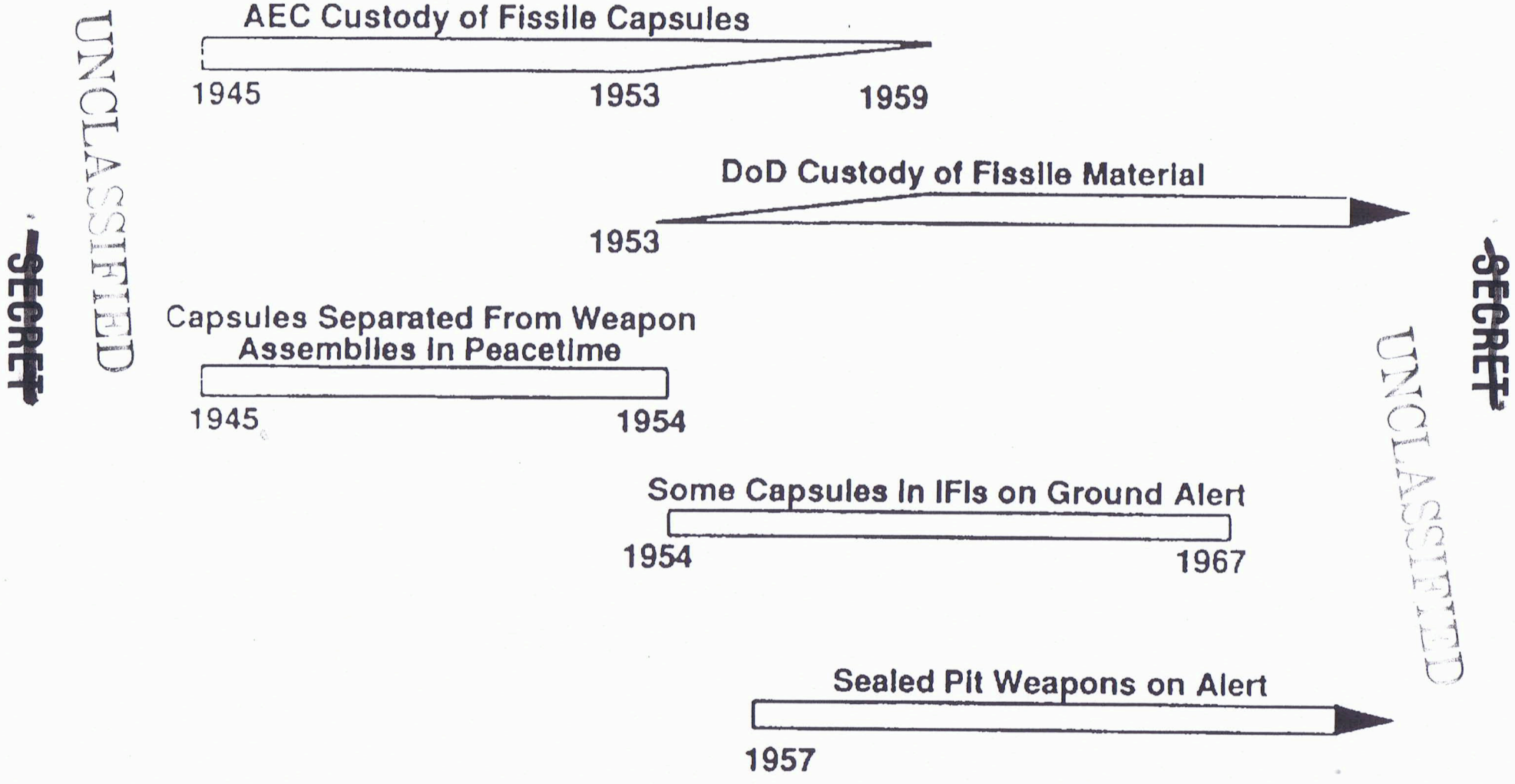
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OPERATIONS & SAFETY DESIGN MUST BE BALANCED



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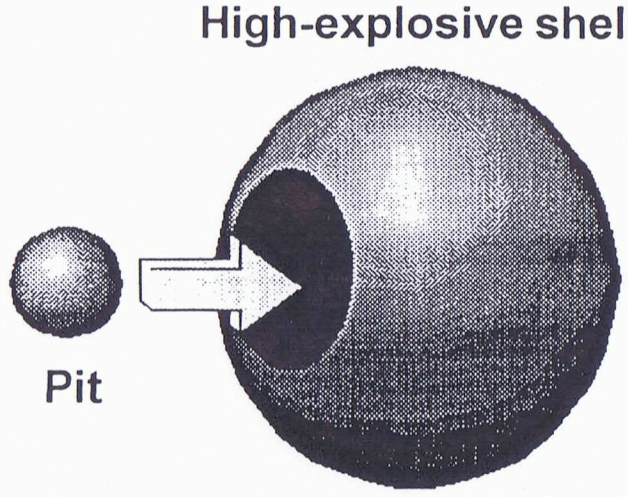
U. S. NUCLEAR DEPLOYMENTS CHANGED



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Manually Inserted Capsules

1948 - 1951



- Safety Theme: Separation of fissile material and HE
- Analysis: Accident must assemble weapon

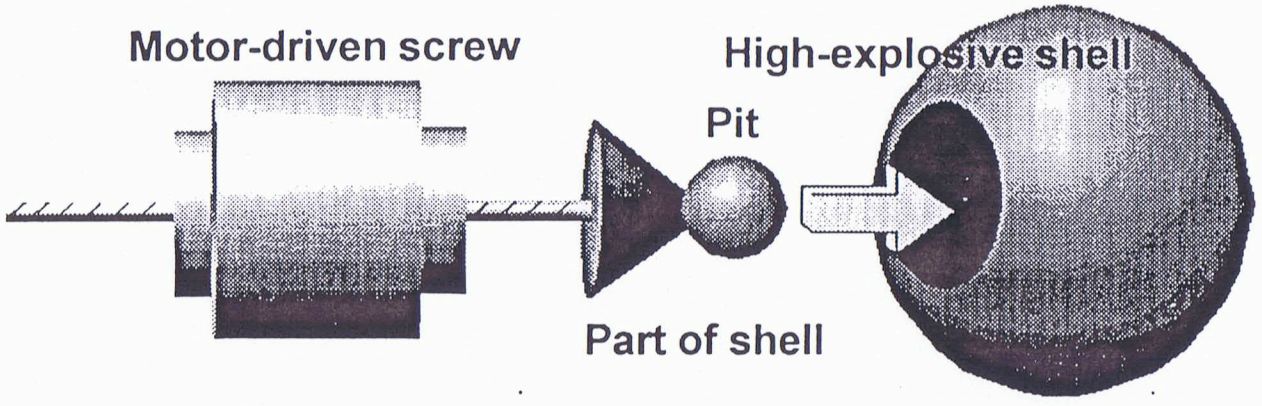
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Mechanically Inserted Capsules

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1952 - 1967



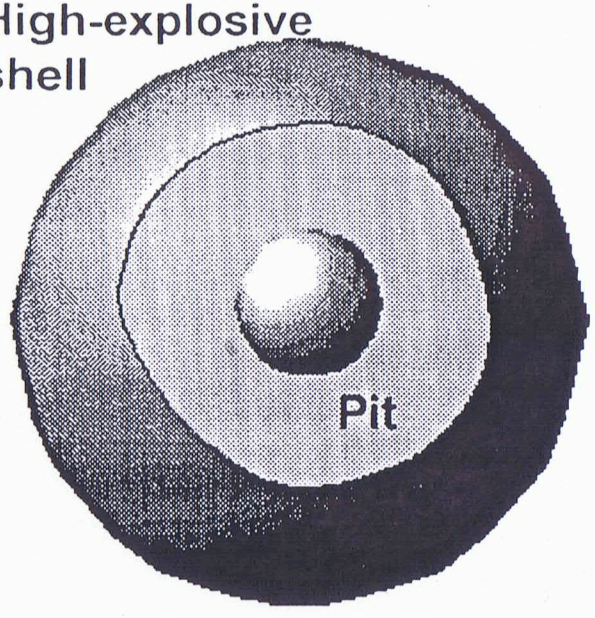
- Safety Theme: Separation of fissile material and HE and electrical isolation
- Analysis: Accident could assemble weapon by operating motor or by mechanical damage

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Sealed-pit Weapons

1957



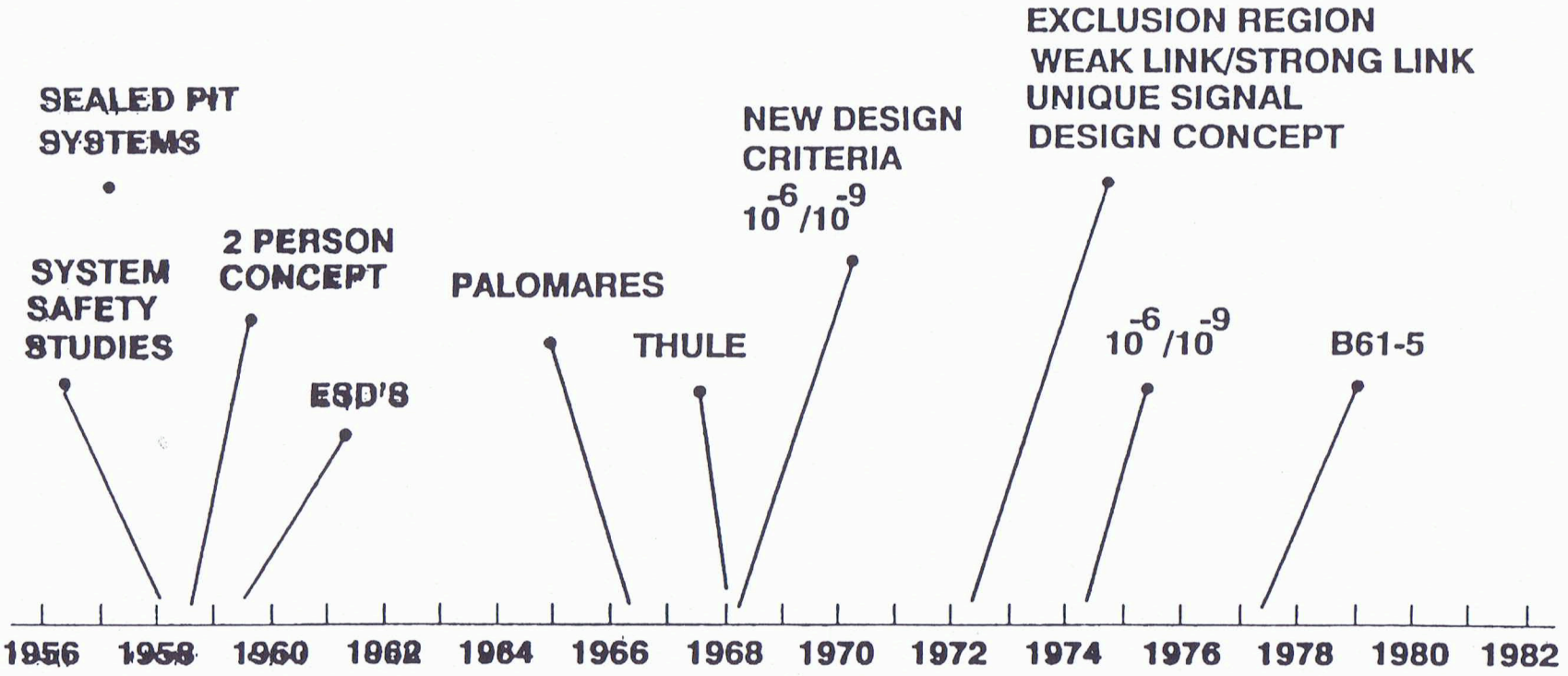
- Safety Theme: Electrical isolation and one-point safety
- Analysis: Accident could generate firing signals; not one-point safe

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EVOLUTION OF NUCLEAR SAFETY



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Early Electrical Isolation Safety Features

1950 - 1970

- Removable safing plugs
- Circuit board and cable isolation
- Removable or external power supplies
- Ready-safe switches
- Thermal fuses
- Environmental sensing devices

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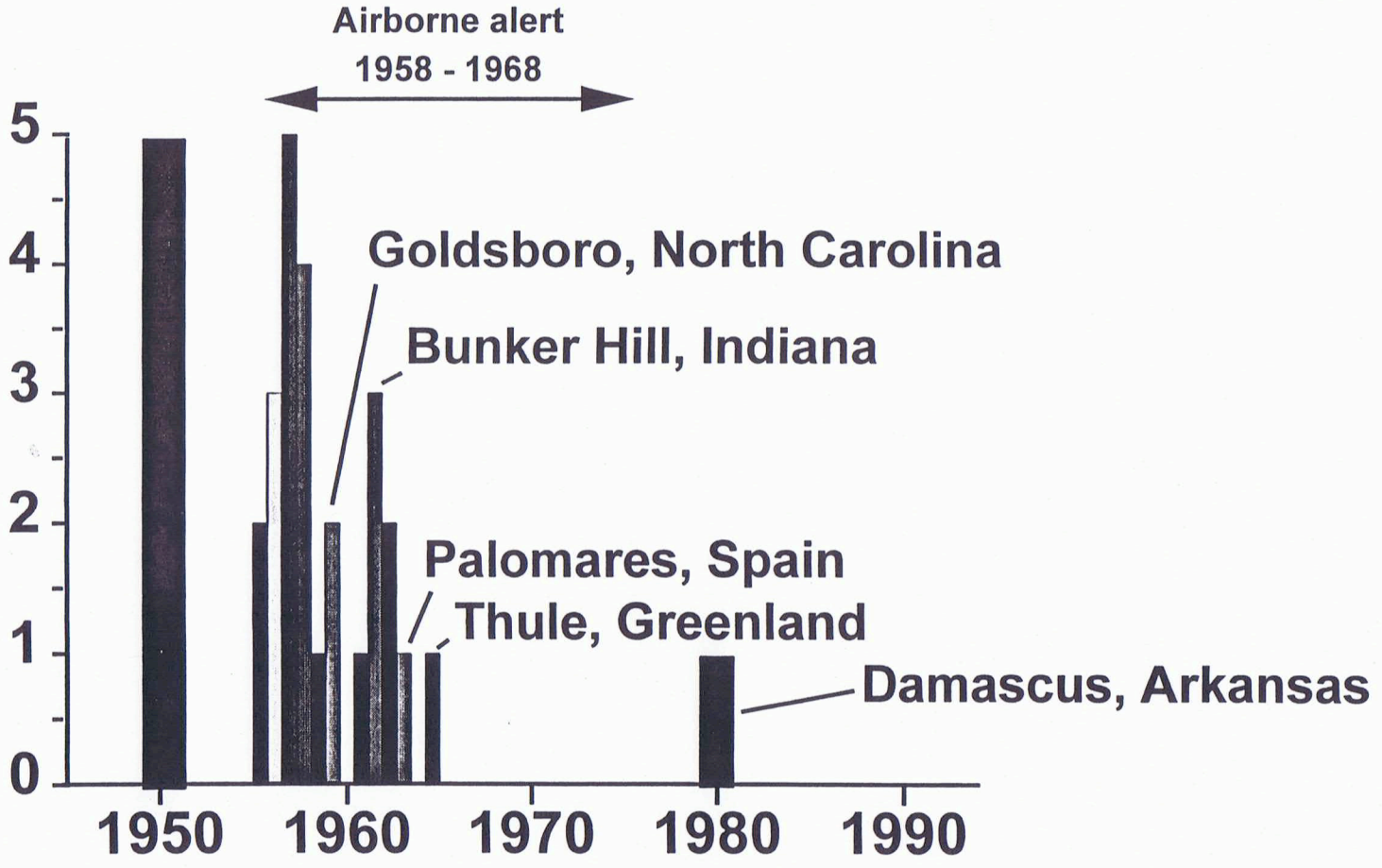
Environmental Sensing Devices (ESDs)

An open switch in the prearming circuits.

It is closed after sensing an environment experienced by the weapon system when enroute to the target.

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US Nuclear Weapon Accidents



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B-52G INCIDENT
GRAND FORKS AFB
15 SEPTEMBER 1980

DURING A CARTRIDGE START FOR AN ALERT EXERCISE, AN ALERT CONFIGURED B-52G EXPERIENCED A FIRE IN THE NUMBER 5 ENGINE. 30 KNOT WIND WAS FORTUITOUSLY BLOWING FROM DIRECTION DIRECTLY AFT OF AIRCRAFT. FIRE WAS FOUGHT FOR THREE HOURS BEFORE FUEL FLOW TO ENGINE POD WAS SHUT OFF AND FLAMES EXTINGUISHED. ENGINE POD AND LEADING EDGE OF WING WERE DAMAGED, ALONG WITH SOME MINOR DAMAGE TO FUSELAGE SKIN.

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Nuclear Weapon Accident--Definition
DOD Directive 5100.52

An unexpected event involving nuclear weapons or nuclear components that results in any of the following:

(1) Accidental or unauthorized launching, firing, or use by U.S. forces or U.S. supported allied forces of a nuclear capable weapon system.

(2) An accidental, unauthorized, or unexplained nuclear detonation.

(3) Non-nuclear detonation or burning of a nuclear weapon or nuclear component.

(4) Radioactive contamination.

(5) Jettisoning of a nuclear weapon or nuclear component.

(6) Public hazard, actual or perceived.

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Accidents (mainly air-delivered systems) eventually led to reexamination of the premature nuclear yield criteria and to the present nuclear detonation safety design criteria.

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Need for a Safety Process

- As the deployment dates for sealed pit weapons approached, the Armed Forces Special Weapons Project (AFSWP) and the Services became uncomfortable with their lack of knowledge and understanding of weapon safety designs.

- 1957, AFSWP convened a safety Board to examine the sealed pit weapon systems becoming available.

- Between 1957 and 1960, the Air Force convened joint safety study groups as weapons entered the stockpile.

- A formal, Joint DoD/DOE Nuclear Weapons System Safety process was established in 1960.

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DoD/DOE Nuclear Weapon Safety Process

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- Joint Safety Study of Each Weapon System and Operational Concept
  - Determine if Weapon System Meets the 4 Qualitative Standards
  - Develop Operation Safety Rules

<u>and</u>

  - Ensure Maximum Safety Consistent with Operational Requirements

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1968 -- DoD/DOE Agree on Premature Nuclear Detonation Design Safety Criteria

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- The probability of a premature nuclear detonation due to component malfunctions, in the absence of any input signals except for specified (e.g. monitoring and control), shall not exceed.

(1) For normal storage and operational environments described in the STS, 1 in 10^{9} per weapon lifetime.

(2) For the abnormal environments described in the STS, 1 in 10^{6} per weapon exposure or accident.

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1968 -- DoD/DOE Agree on One-Point Detonation Design Safety Criteria

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One Point Safety

a. In the event of a detonation initiated at any one point in the high explosion system, the probability of achieving a nuclear yield greater than four pounds TNT equivalent shall not exceed one in one million.

b. One-point safety shall be inherent in the nuclear design, that is, it shall be obtained without the use of a nuclear safing device.

Four Pounds

"The four pounds TNT equivalent evolved from a U.S. Navy requirement based upon personnel exposure in the engine room of an aircraft carrier resulting from a small nuclear yield occuring on the flight deck 50 feet above the engine room (Ref. 5). A study concluded that a detonation giving a nuclear contribution equivalent to 44 pounds of TNT would result in a 50% sickness dose (SD_{50}) of 200 neutron rad to personnel in the engine room. To be conservative, a reliability factor of 10 was applied and the result rounded to four pounds. Another study, conducted in 1967 by the U.S. Army Nuclear Defense Laboratory, concluded that 8.5 pounds TNT equivalent would produce 200 neutron rad at 50 feet. This figure had a reliability factorr of two applied and the result rounded to four pounds, also."

Reference: "One-Point Safety," Defense Science, LANL, March-April 1983

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Conclusion of Stockpile Study

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New approach to nuclear weapon safety needed

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Safety Goals for Abnormal Environments

- Assured, predictable, safe response of the warhead electrical system
- Maintain predictable, safe response until intended use
- Minimize safety critical components and dependence on knowing accident scenario

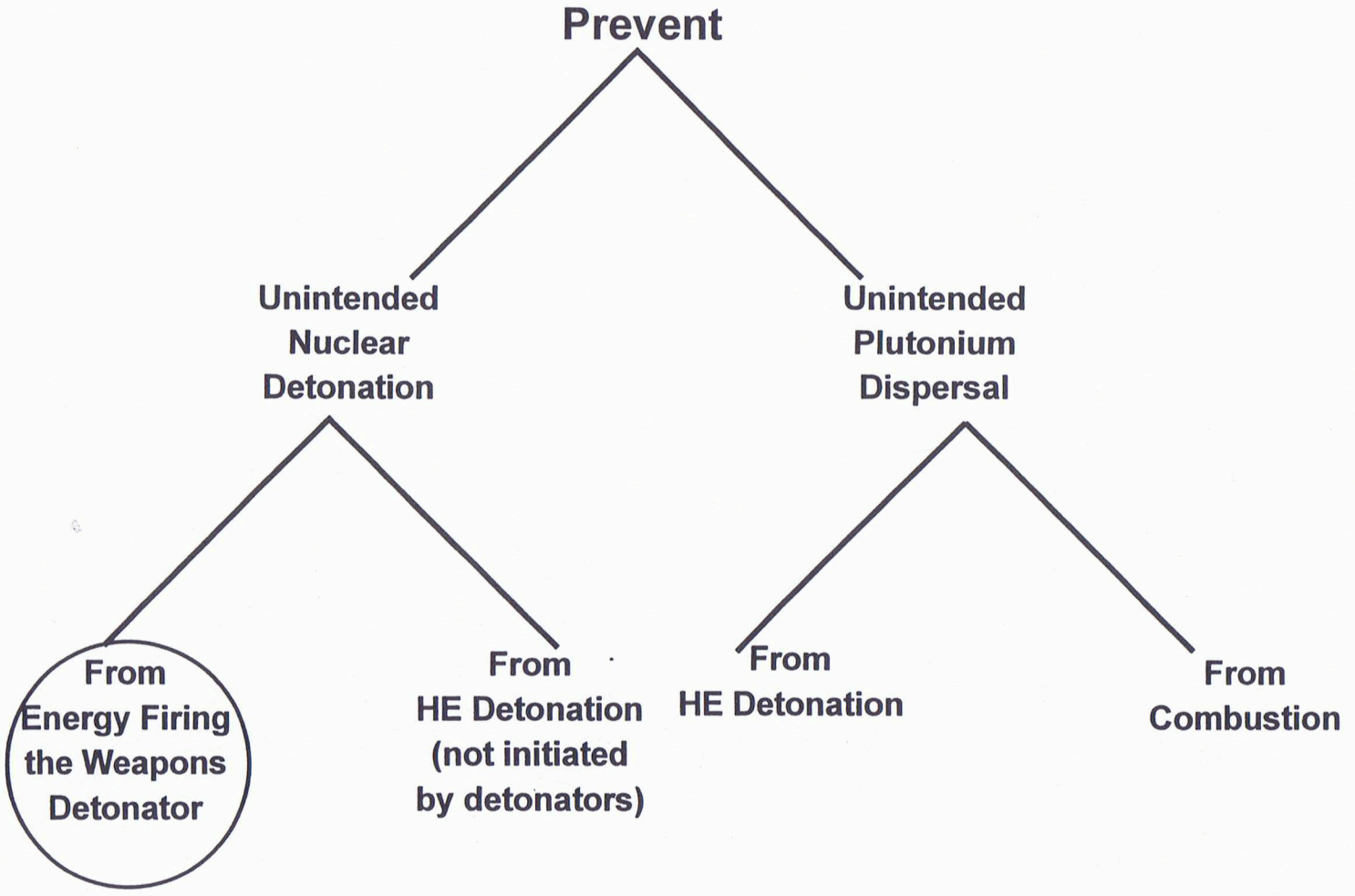
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Modern Nuclear Safety -- The 4 I's

- Isolation
  - Barriers
  - Stronglink switches
- Incompatibility
  - Unique signals
- Inoperability
  - Co-location of stronglinks and weaklinks
- Independence of safety subsystems

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MORE SPECIFICALLY THE SAFETY GOALS ARE TO



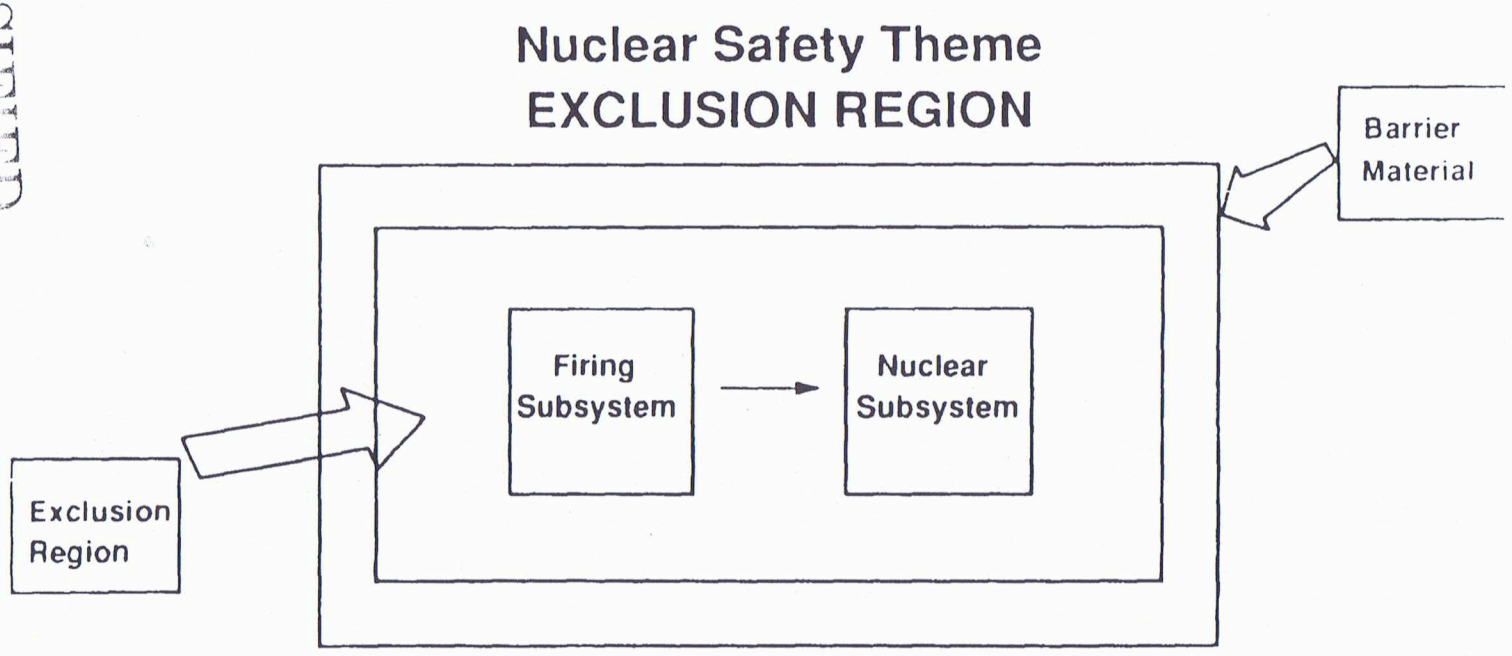
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MODERN SAFETY DESIGN PHILOSOPHY

Co-locate detonation-essential components and protect them from abnormal environments by an exclusion region



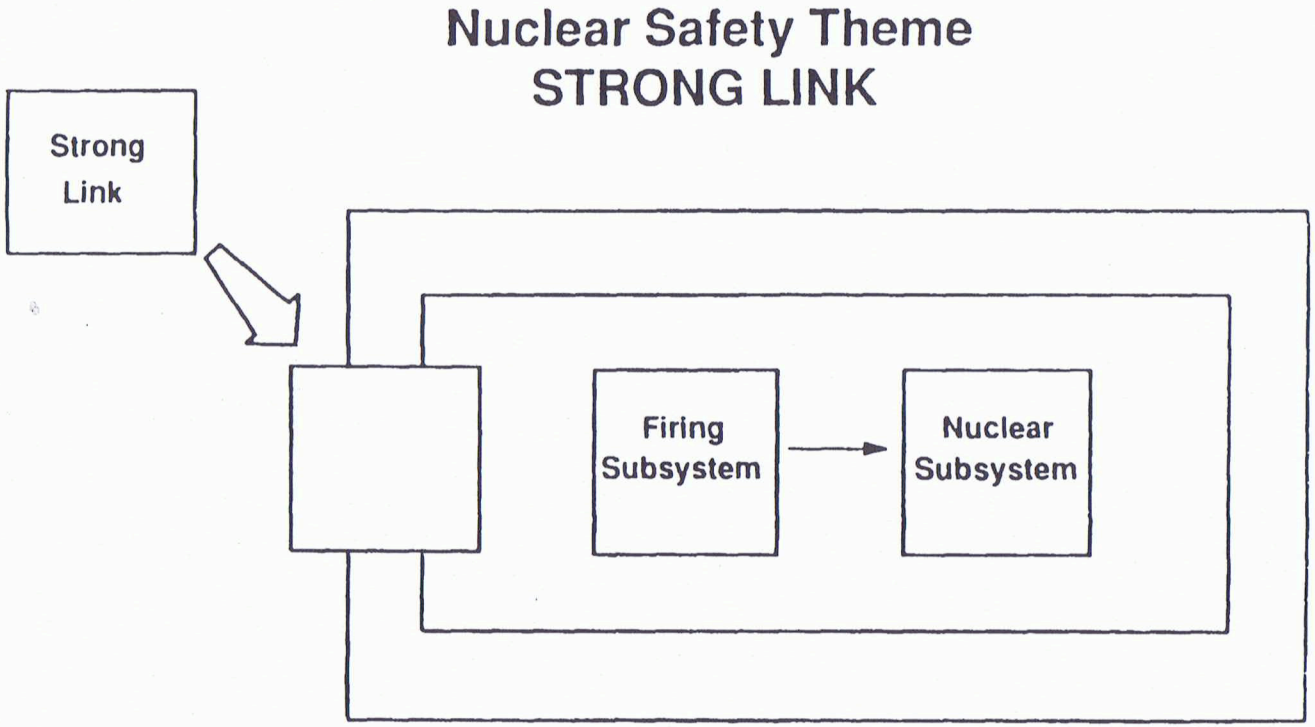
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MODERN SAFETY DESIGN PHILOSOPHY (cont)

Allow energy/signals into the exclusion region only through a strong link

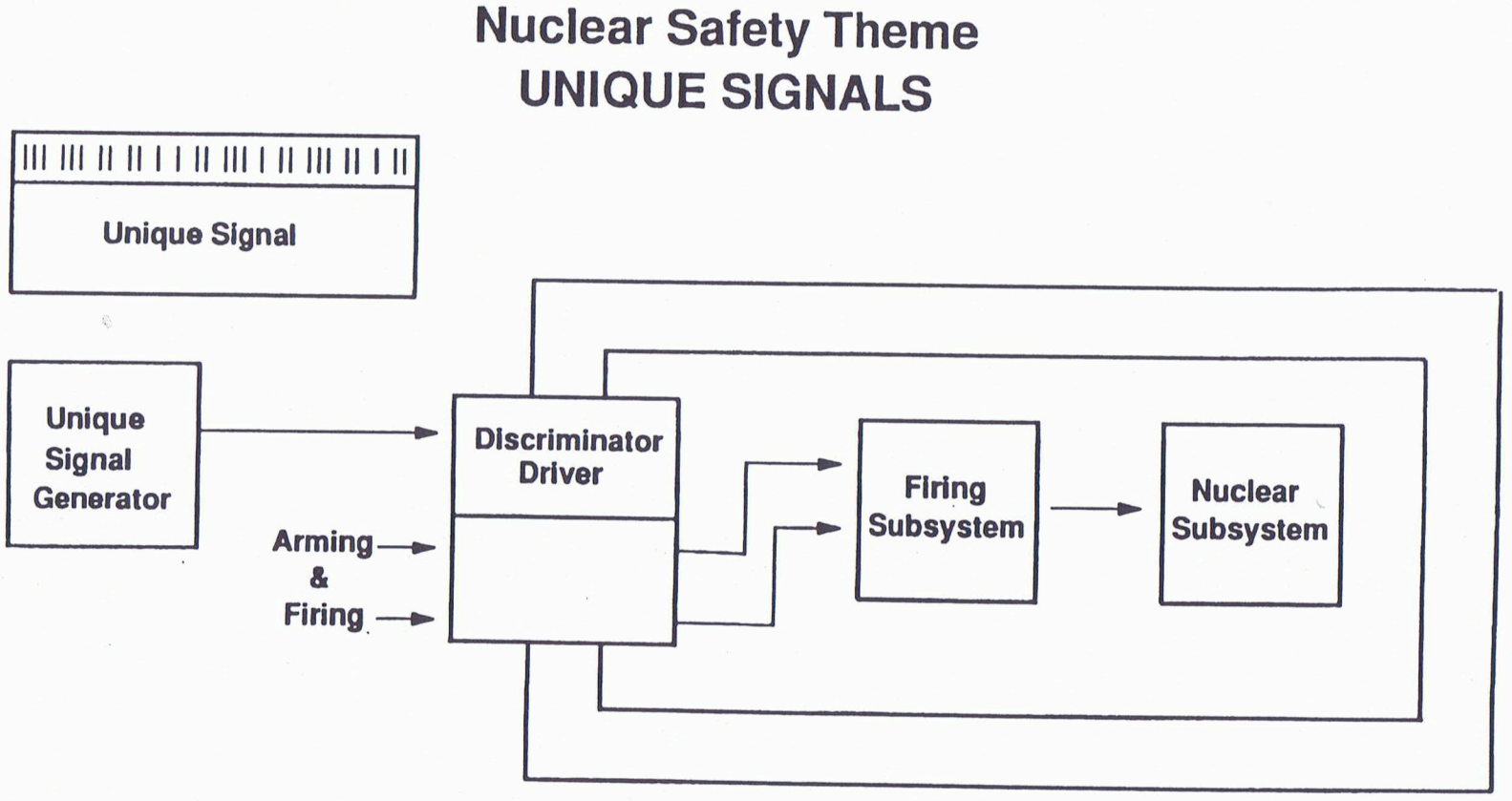
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Control the strong link(s) with a unique signal not duplicated elsewhere in the system

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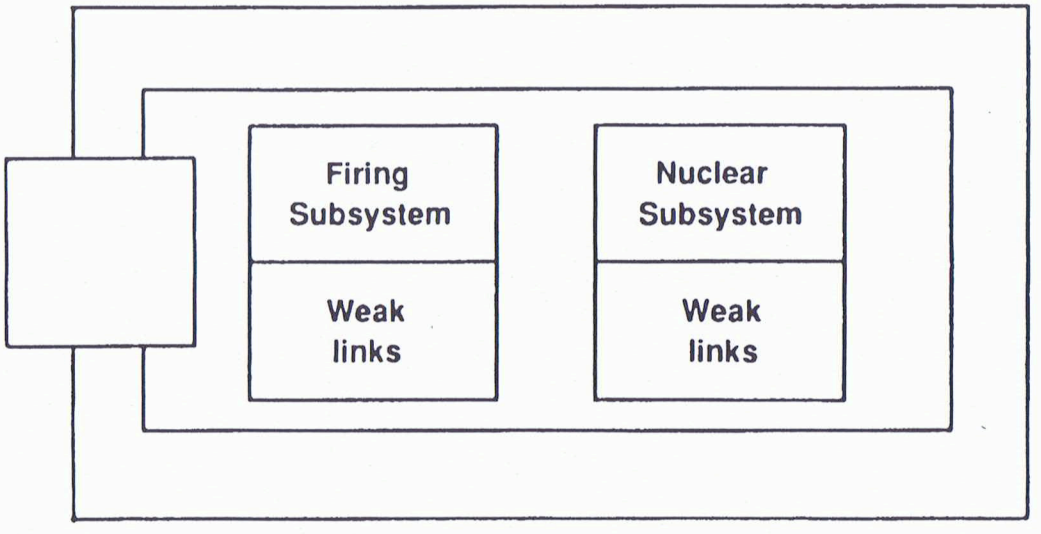
MODERN SAFETY DESIGN PHILOSOPHY (cont)

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Finally, to address credible but catastrophically severe environments, co-locate *weak link* detonation-essential components which will predictably become inoperable prior to the barrier or strong links losing their integrity.

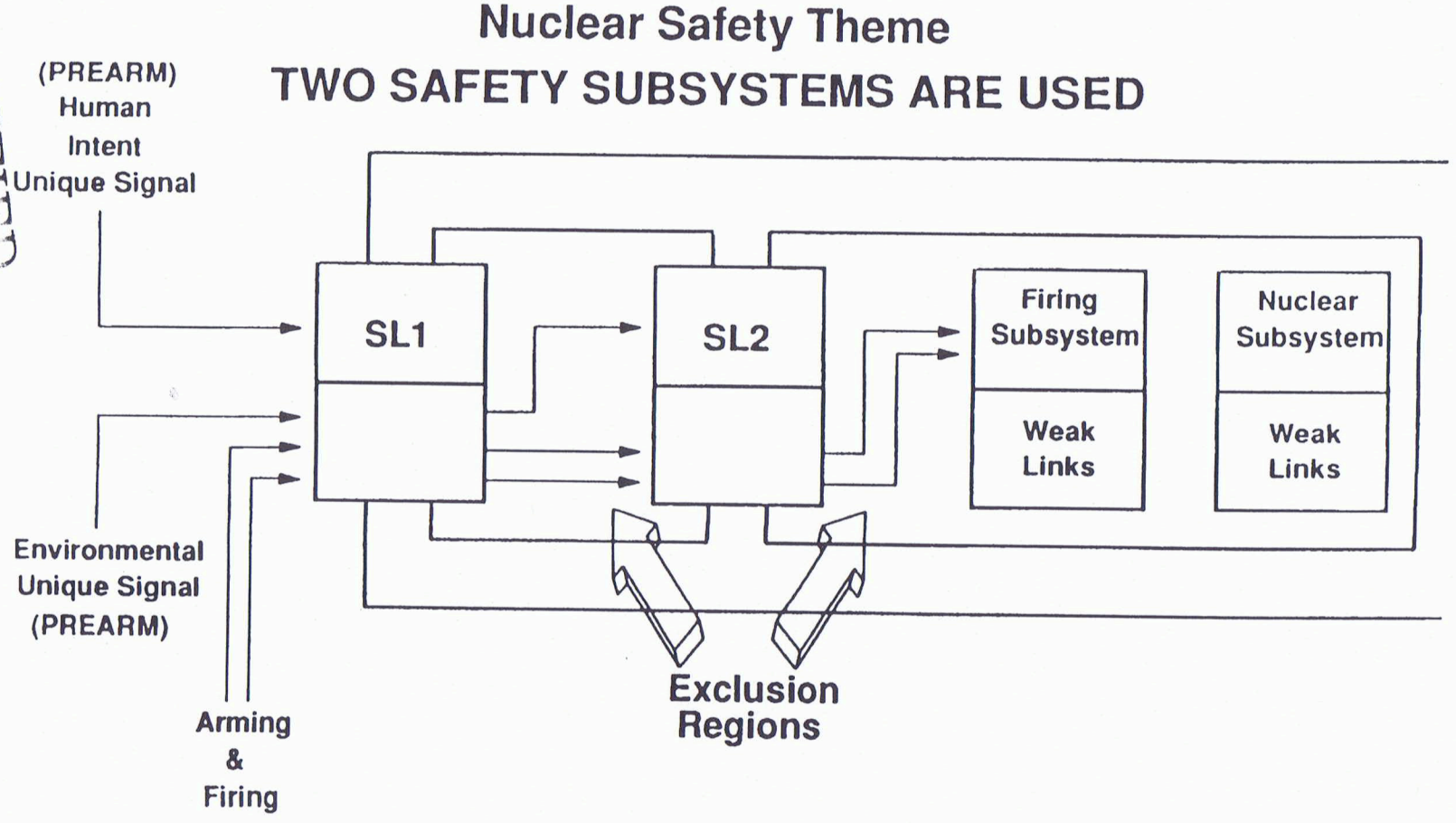
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Nuclear Safety Theme
WEAK LINKS



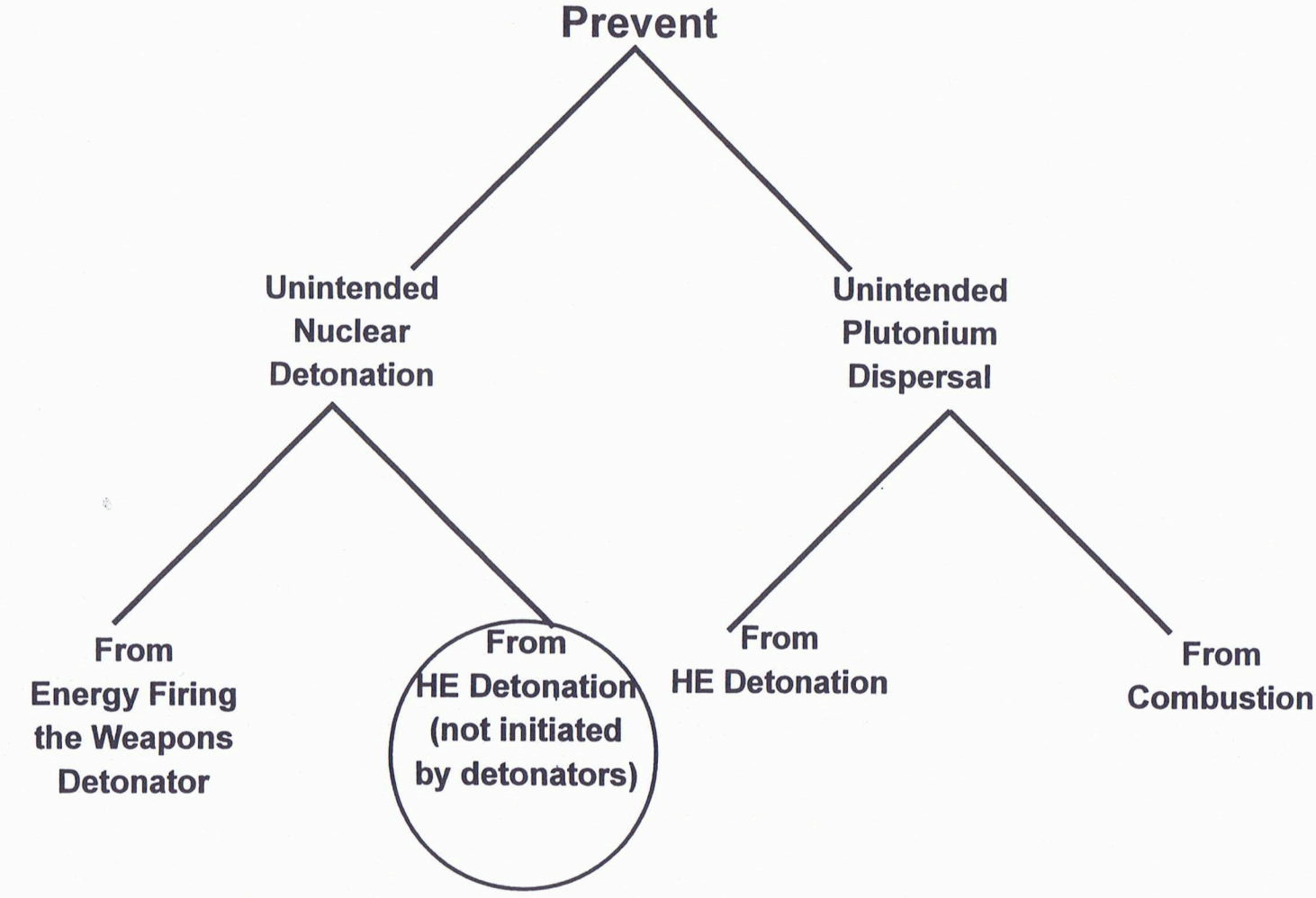
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BECAUSE THE REQUIREMENT (LESS THAN ONE-IN-A-MILLION) IS QUITE STRINGENT



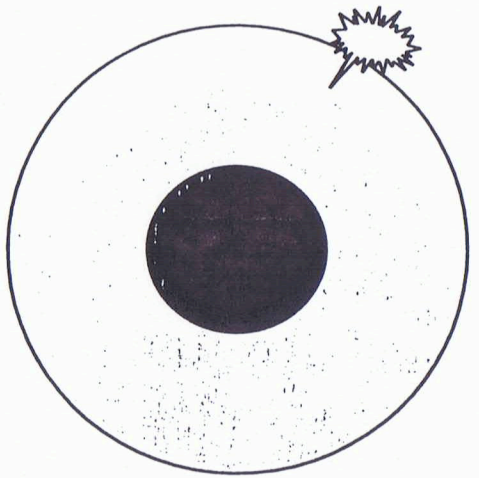
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ONE POINT SAFETY



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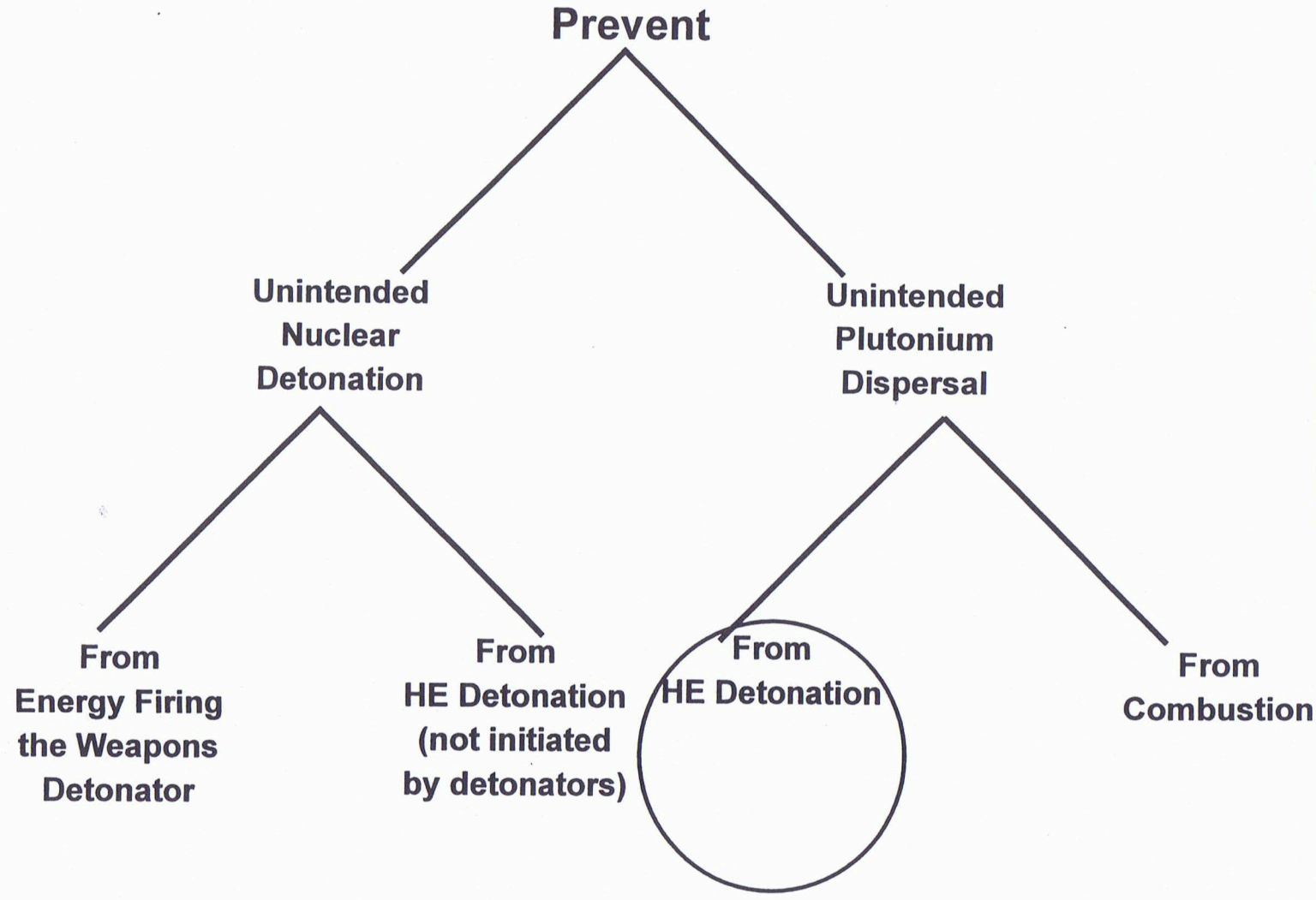
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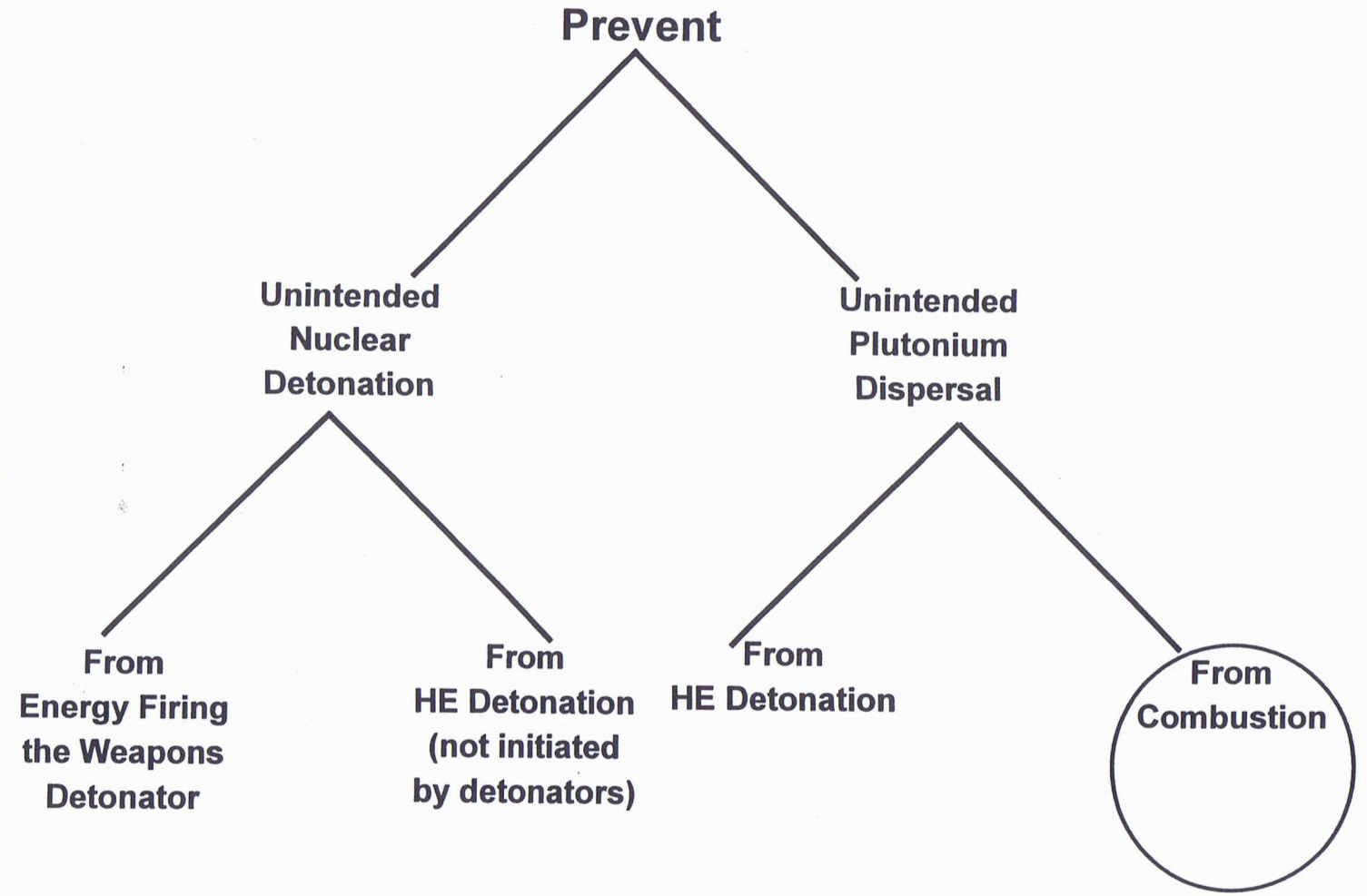
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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

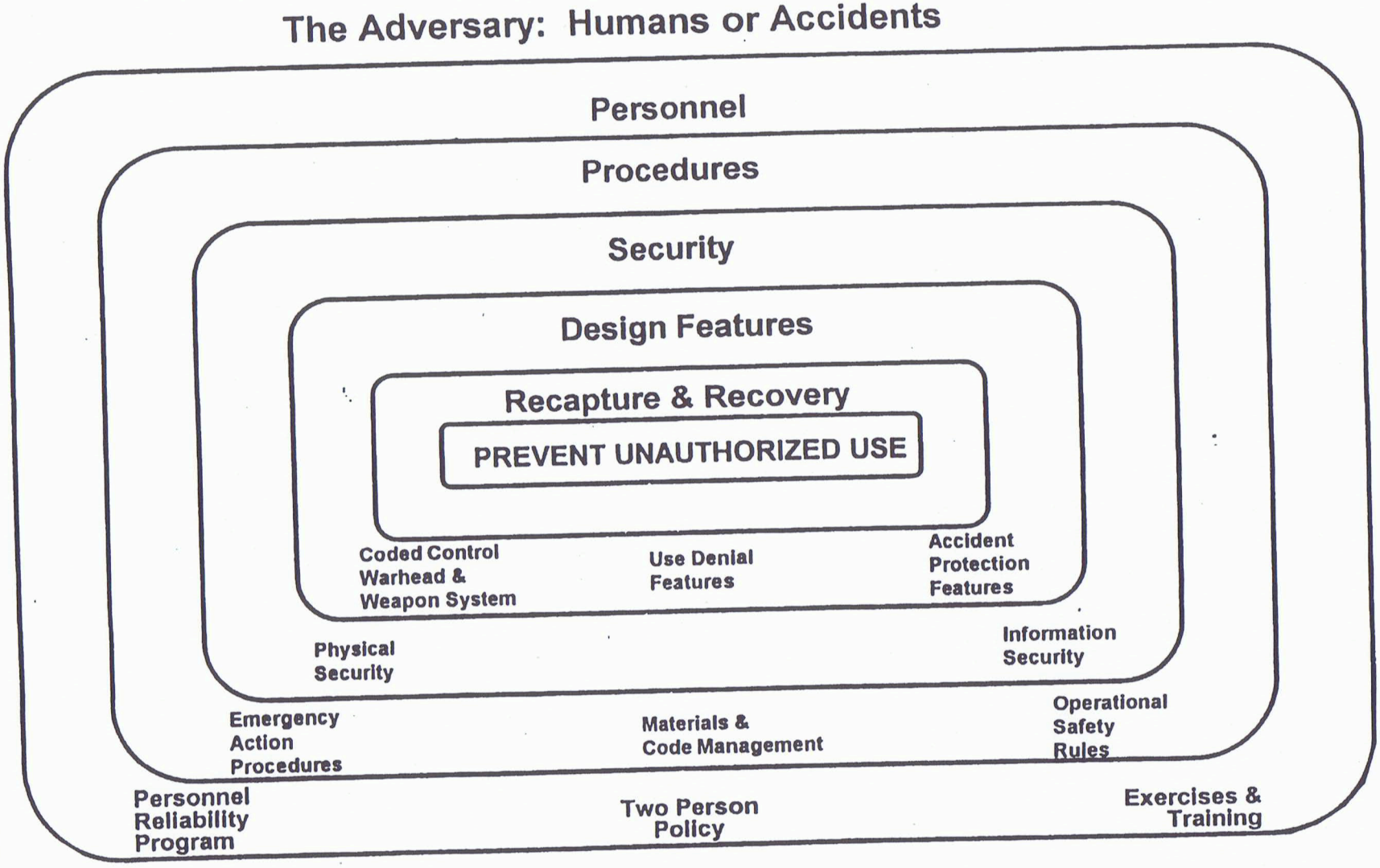
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SESSION VIII

- PROTECTION OF NUCLEAR WEAPONS
- ACCESS CONTROL MEASURES
- USE CONTROL MEASURES

Layered Positive Measures to Assure Against Unauthorized Use



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THE NUCLEAR WEAPONS ACCESS CONTROL AND USE CONTROL PROGRAMS TRY TO:

- Prevent unauthorized access to a nuclear weapon
- Prevent loss of custody of a nuclear weapon
- Prevent an intended (but unauthorized) nuclear explosion
- Prevent an intended (but unauthorized) dispersion of SNM

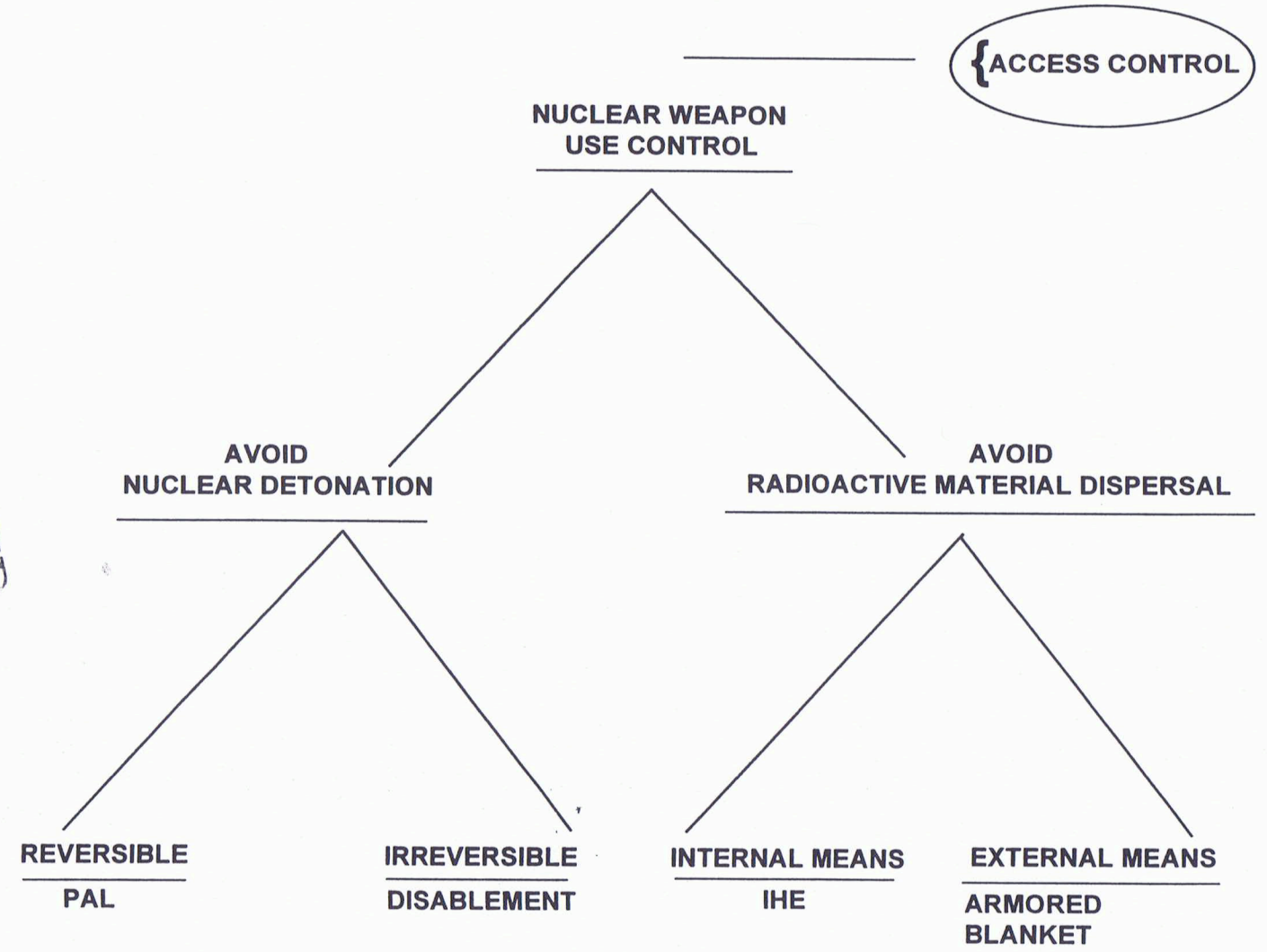
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ACCESS CONTROL (TO THE WEAPON) IS ANALOGOUS TO ACCIDENT PREVENTION - IF NO UNAUTHORIZED ACCESS (ACCIDENT) OCCURS, THERE IS LESS POTENTIAL FOR A PROBLEM.

HOWEVER, USE CONTROL FEATURES STILL ASSUME SOME LEVEL OF ACCESS CONTROL EXISTS OR CAN BE REESTABLISHED.

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ENVIRONMENTAL SENSING DEVICES (ESDs)

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An open switch in the prearming circuits.

It is closed after sensing an environment experienced by the weapon system when enroute to the target.

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INTENDED USE AND NON-INTENDED USE MODE OPERATION

- **Intended Use Mode**

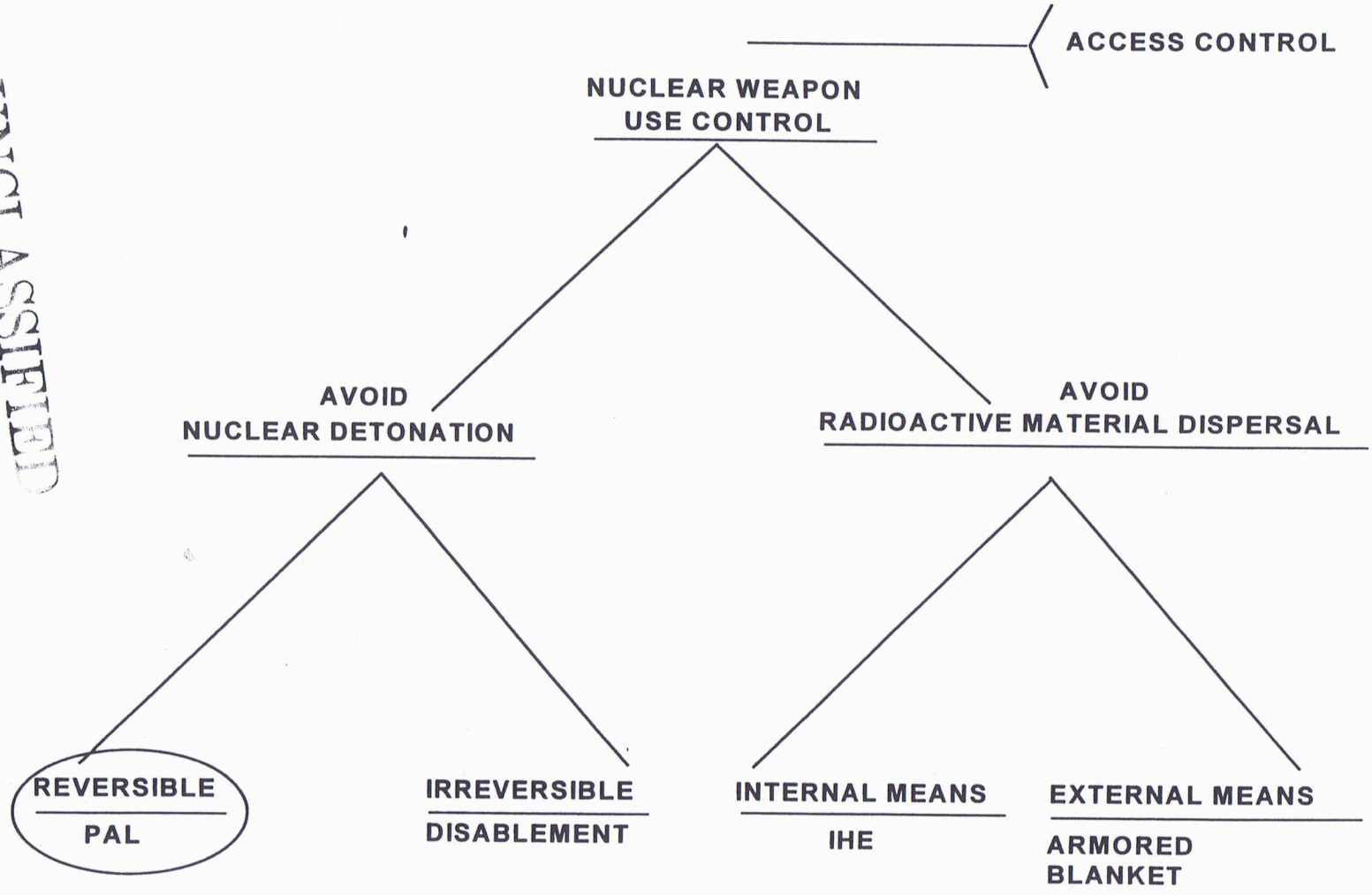
  —**Use of the warhead, weapon and weapon system as designed to operate when used against a target.**

- **Non-Intended Use Mode**

  —**Detonation "in place"; operation of weapon/weapon system in other than intended use mode.**

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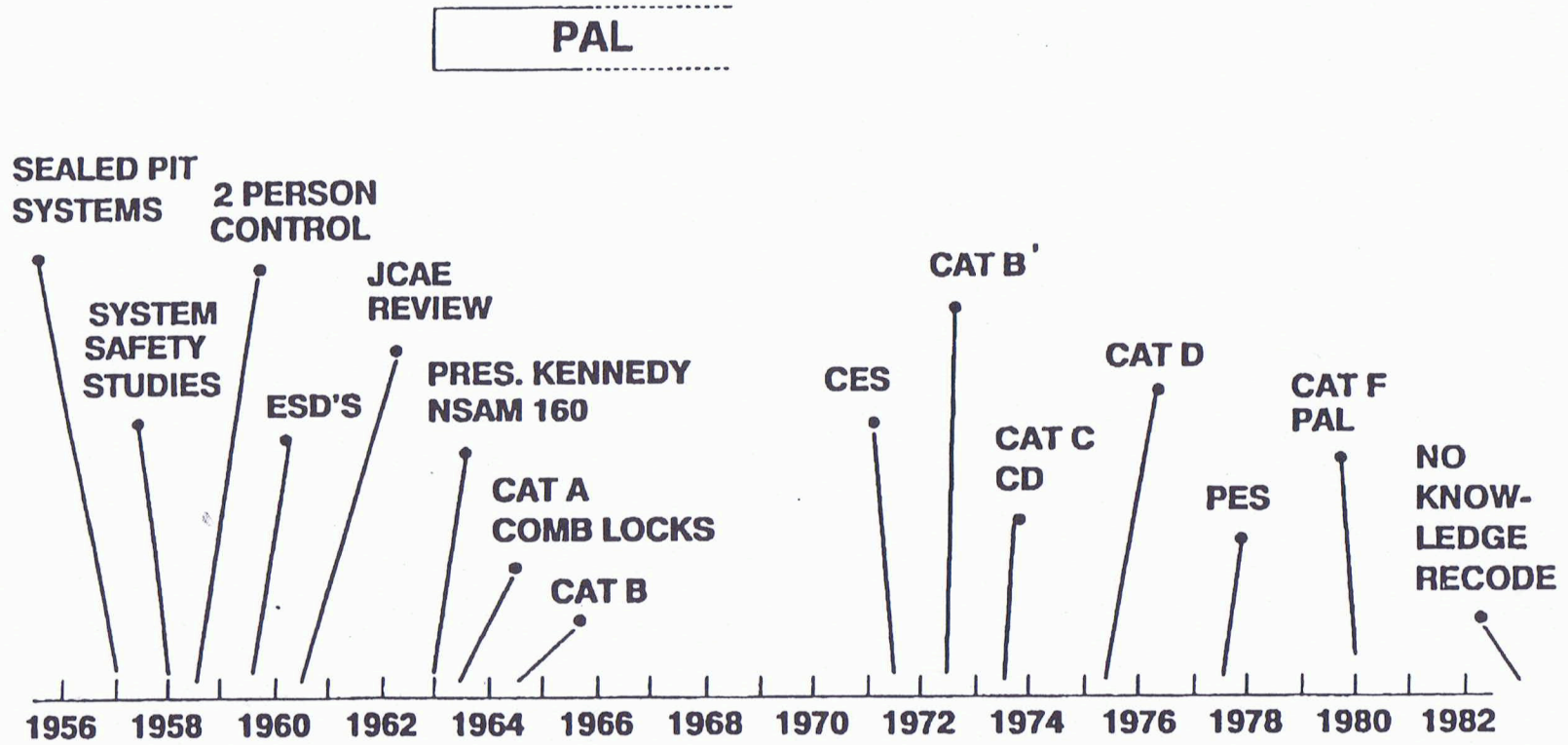
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PAL (Permissive Action Link)

A code controlled switch which interrupts the warhead's arming circuit

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EVOLUTION OF NUCLEAR WEAPON USE CONTROL



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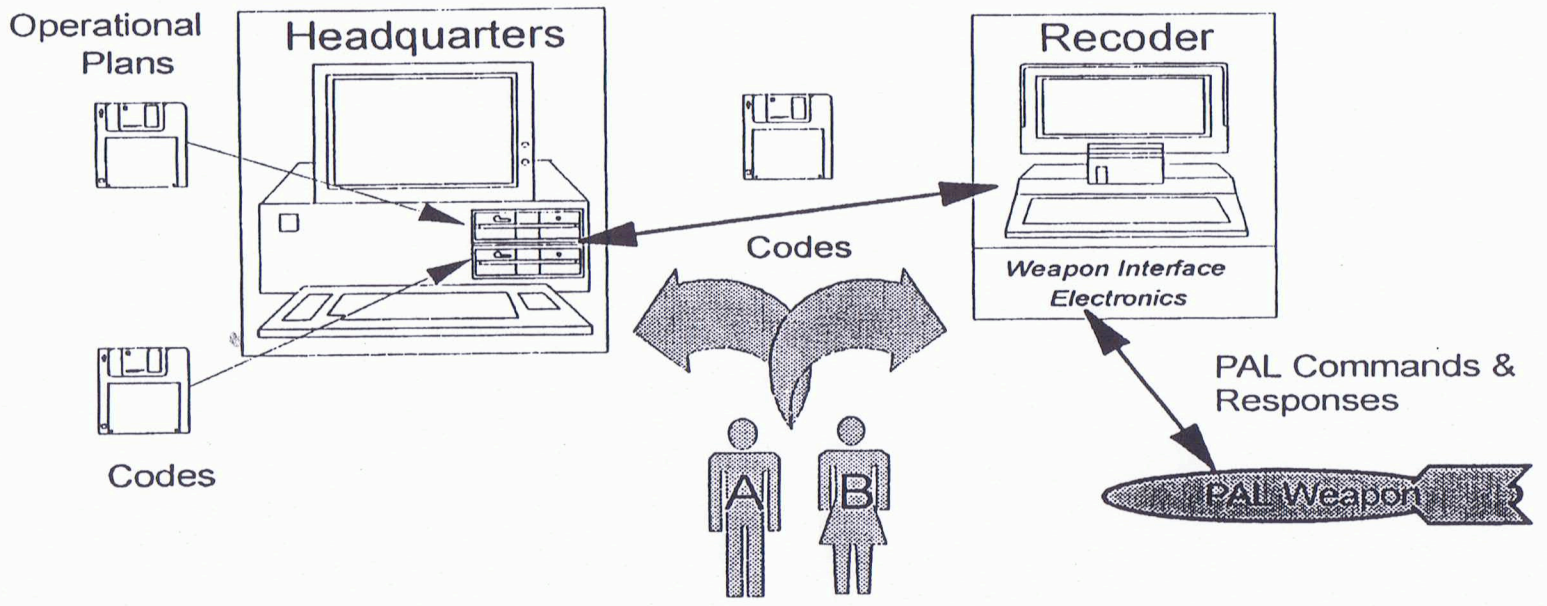
PERMISSIVE ACTION LINK

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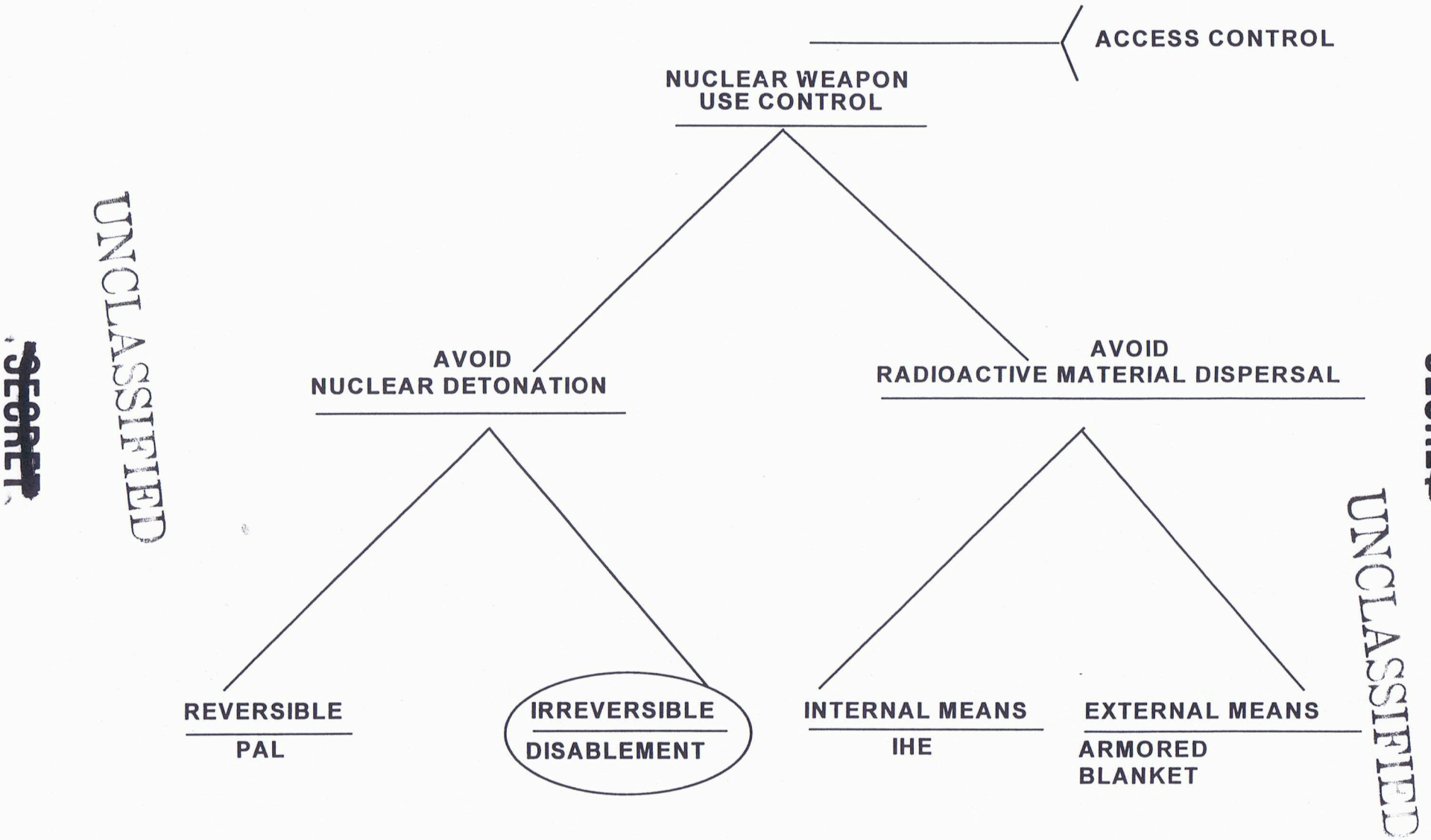
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PAL Code Management



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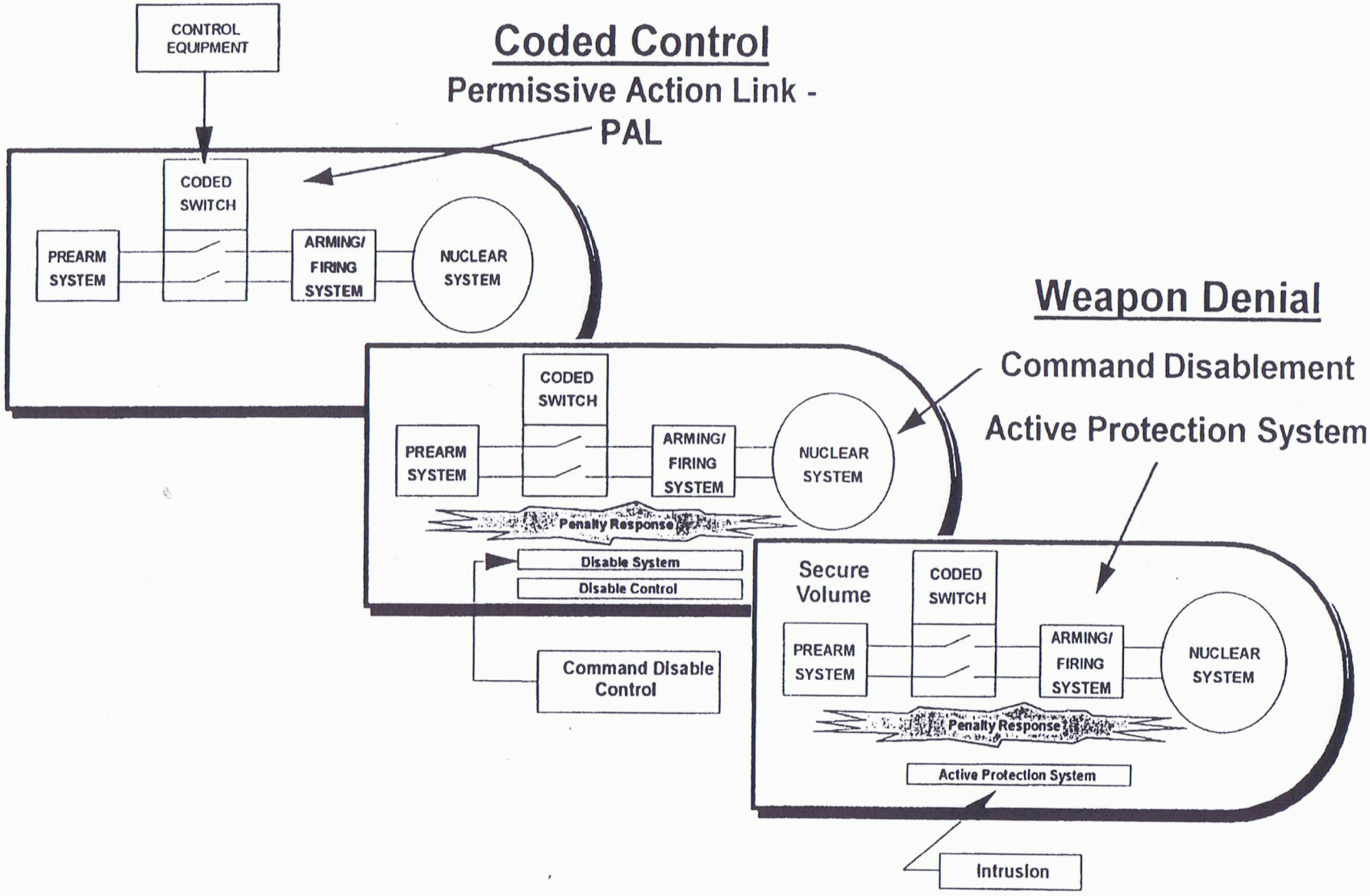
DISABLEMENT

- When initiated, disables certain key nuclear detonation-essential components.

- Non-violent outside the weapon case.

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Warhead Use Control



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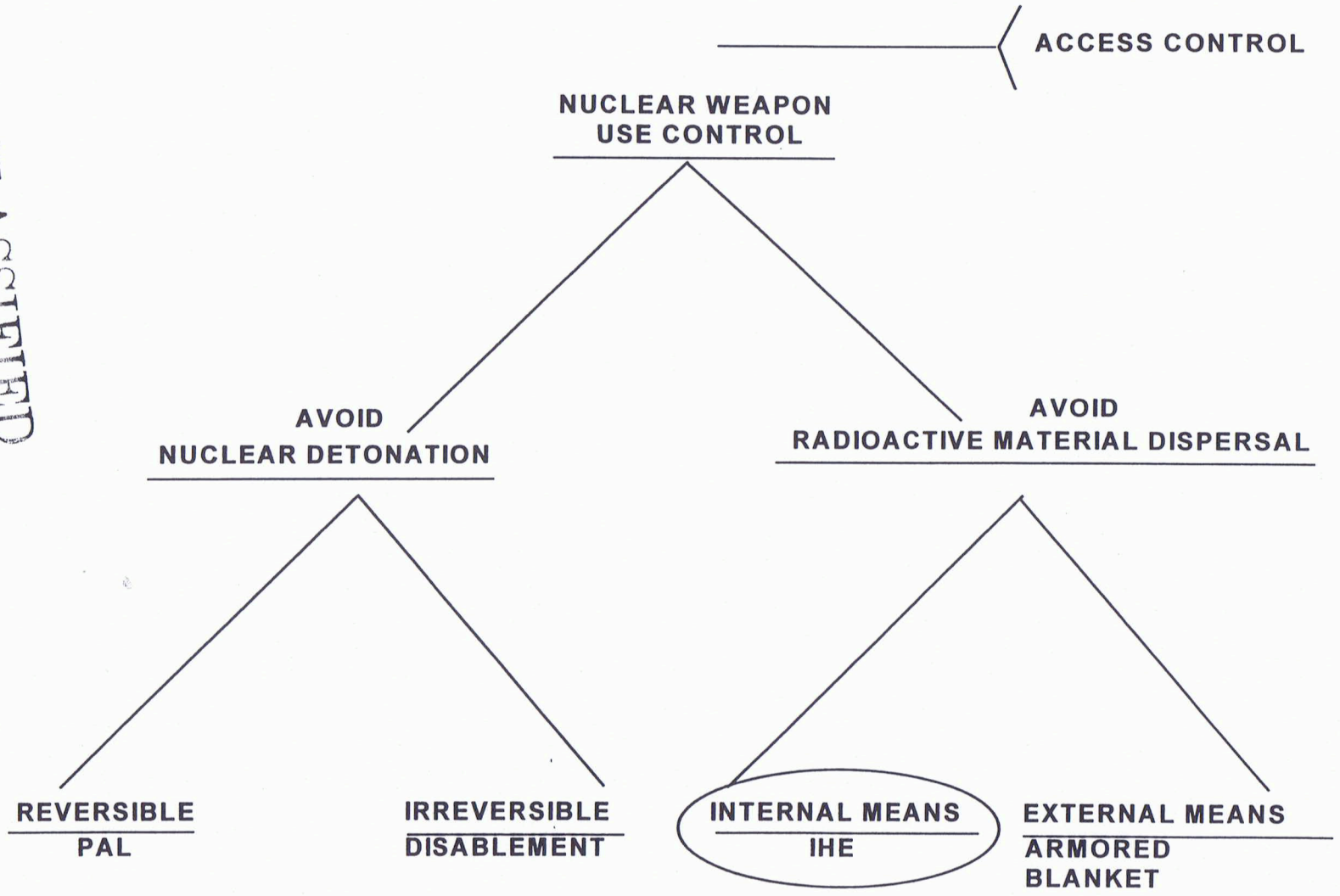
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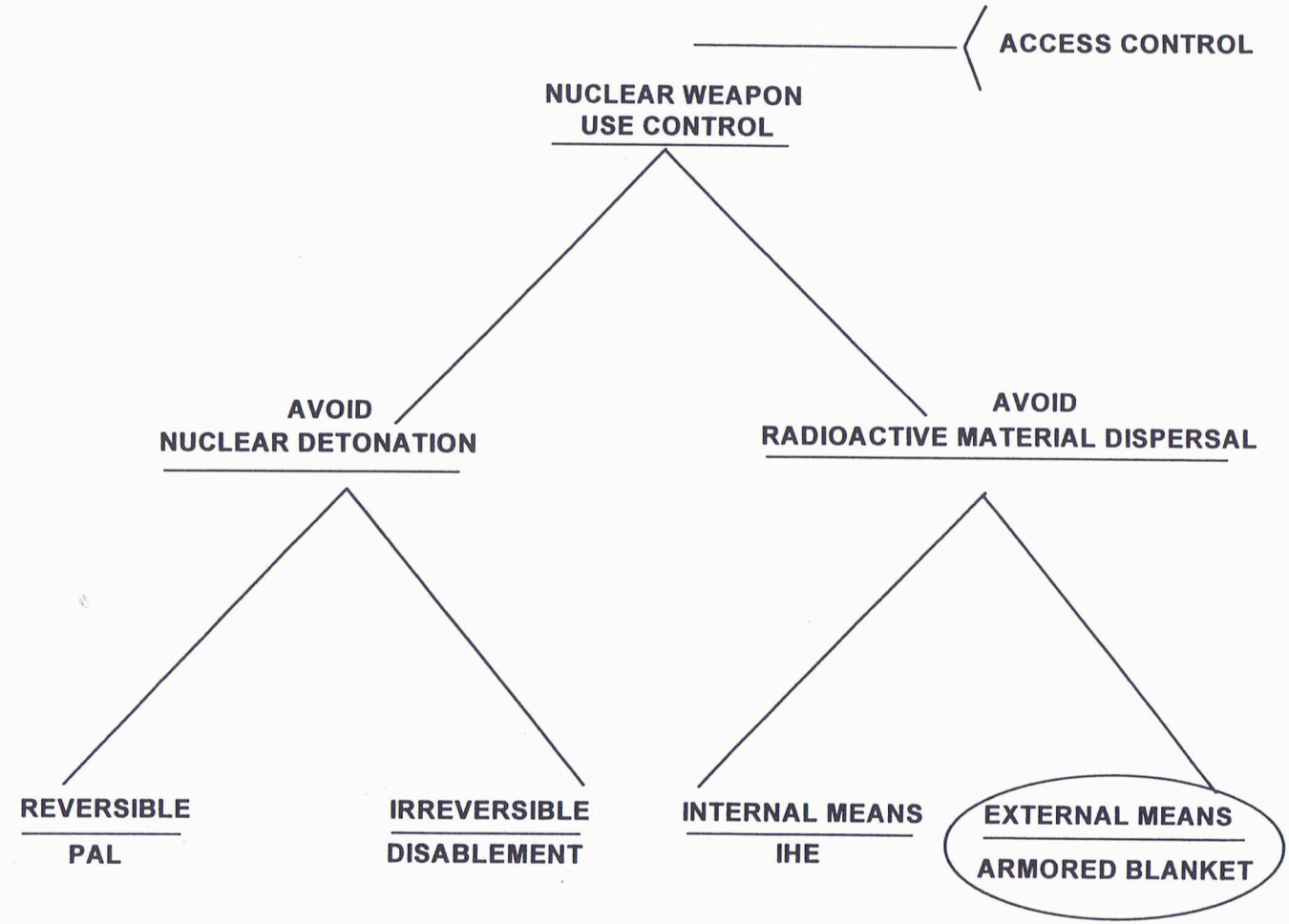
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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION IX

AIRCRAFT WEAPON SYSTEMS

- WEAPON SYSTEMS
- REQUIREMENTS
- NUCLEAR WEAPONS SYSTEMS FOR ENDURING STOCKPILE
- AIRCRAFT INTERFACE

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SANDIA NATIONAL LABS AIRCRAFT COMPATIBILITY DEPARTMENT

- Our charter is to ensure the Department of Energy that a capability exists between US nuclear weapons and the aircraft they are carried on throughout their life in the inventory.
- Our department was established in the early 1960's.
- We work with the military, aircraft contractor, and Sandia's weapon departments in the design of the aircraft/weapon interface.
- We define the requirements the military and contractor must comply with before final design approval can be granted.
- We conduct a wide range of electrical and mechanical tests to verify a capability exists.

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An Overview of the Evolution of Aircraft Monitor and Control (AMAC) Systems

- The AMAC acronym was created to describe the dedicated "black boxes" that monitor and control nuclear weapons.
- From 1945 to 1961, no standard weapon interface existed. Early bomb technology drove the design of the AMAC Systems.
- Little Boy (B1) and Fat Man (B2) were controlled by an AMAC known as a Flight Test Box (FTB). The FTB could measure battery voltages, turn on radars, and could verify certain components had not failed. Two manually inserted arming plugs were used to arm the weapons prior to pressurization of the cockpit at 8000ft.
- Manually inserted arming plugs were also used on the B3 (production Fat Man) and B4-0 bombs.
- 1950 saw the first bomb (B5) to incorporate a cockpit controlled inflight insertion (IFI) mechanism for enhanced nuclear safety. This device was the forerunner of the Ready/Safe switch, and it required a new AMAC to control this bomb feature.

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An Overview of the Evolution of Aircraft Monitor and Control (AMAC) Systems

- 1952 saw the first fighter-carried bomb (B7). It had an AMAC controlled retractable fin for ground clearance.
- By 1952 there were three AMAC systems for bomber aircraft and one for fighter aircraft.
- In the late '40s and early '50s AMAC systems were built around the specific needs for the bombs, not the aircraft.
- In 1954 Sandia started a program to standardize AMAC functions for new weapons under development.
- The result of this effort resulted in the T249 AMAC for bomber and fighter aircraft usage.

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An Overview of the Evolution of Aircraft Monitor and Control (AMAC) Systems

- New bombs designed during the mid to late '50s were made compatible with the T249 rather than building a unique AMAC for a specific bomb.
- AMAC design specifications, defined jointly by the DOE and DoD, first appeared in December 1961.
- AMAC specifications such as Bomber System A, Fighter System A & B, and Aero 6B were the forerunners of todays AMAC systems.
- Today's nuclear-capable aircraft, with the exception of the B-52 ALCM/ACM AMAC Systems, have what is known as a System 1 AMAC interface.
- The System 1 specification first appeared in September 1963.

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System 1 Offered Many Improved Features in Safety and Compatibility

- A current-limited Monitor State allowing weapon status to be checked without applying Safe power.
- Dedicated weapon status monitor pins for Safe, Arm, Permissive Action Link (PAL), and Weapon Present ID.
- [redacted] (3)
- Category (CAT) B PAL [6/63] and CAT D PAL [8/75] enhanced weapon security.
- Unique Signal Generator (USG) [8/75] enhanced weapon safety in abnormal environments.
- Command Disable (CD) [10/81] provided the ability to render a weapon useless from the cockpit.

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Conclusion

- All aircraft nuclear weapon interfaces built to date have been analog.
- AMAC systems have transitioned from separate to integrated designs.
- A System 2 AMAC specification, based on MIL-STD-1760, exists that defines a digital interface for possible use in future nuclear weapons.
- The number of nuclear capable aircraft has decreased considerably in recent years.

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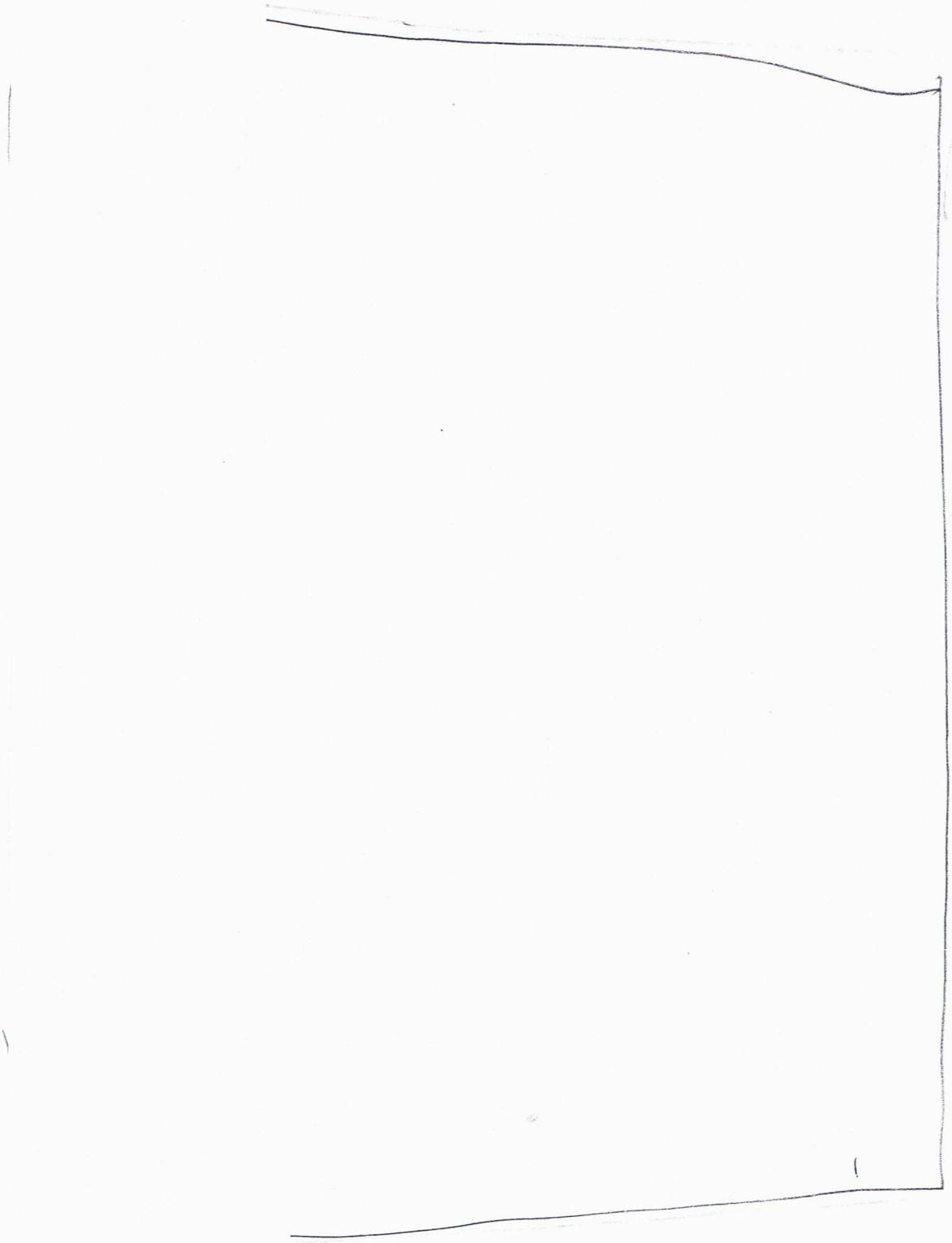
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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION X

- Nuclear Weapons Dismantlement

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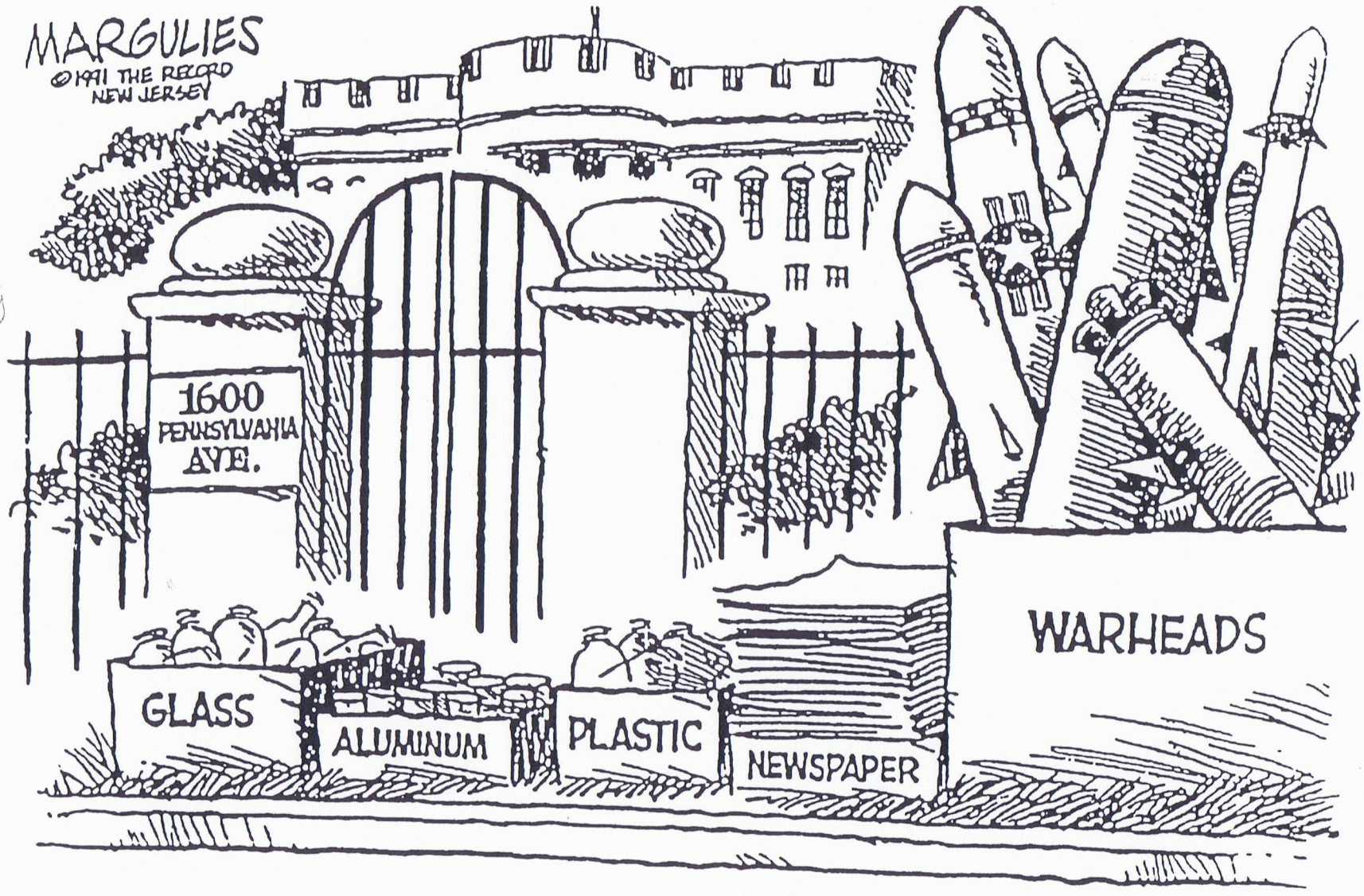
Dismantlement Topics

- Process
- Magnitude
- DOE/Labs Organiztion
- Technology Applications
- Laboratories Increased Presence at Pantex
- Lab-to-Lab Interchanges with Russians

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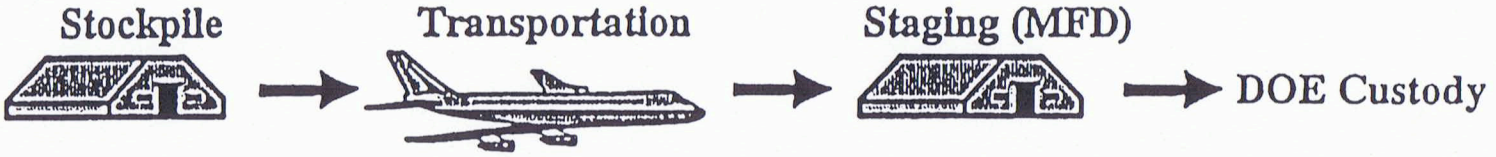
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Nuclear Stockpile Dismantlement Process

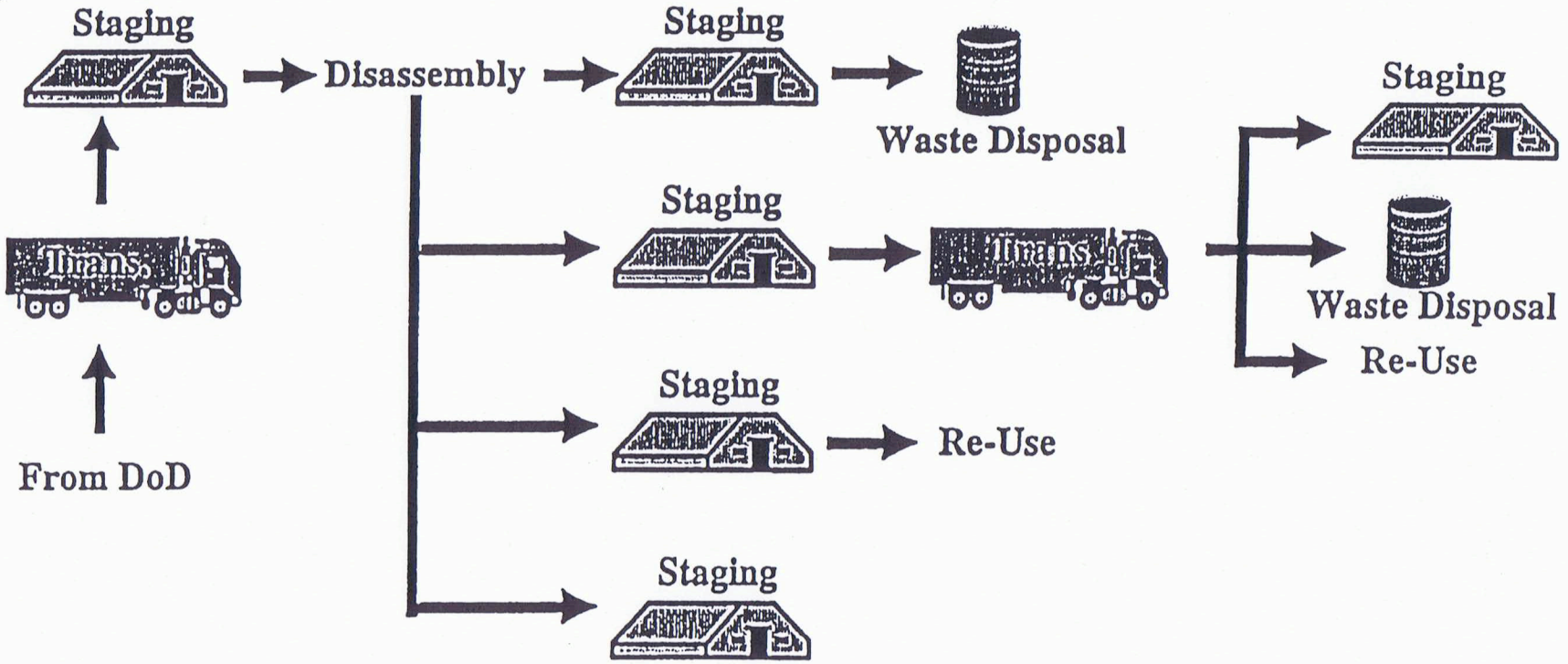
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DoD Custody



DOE Custody

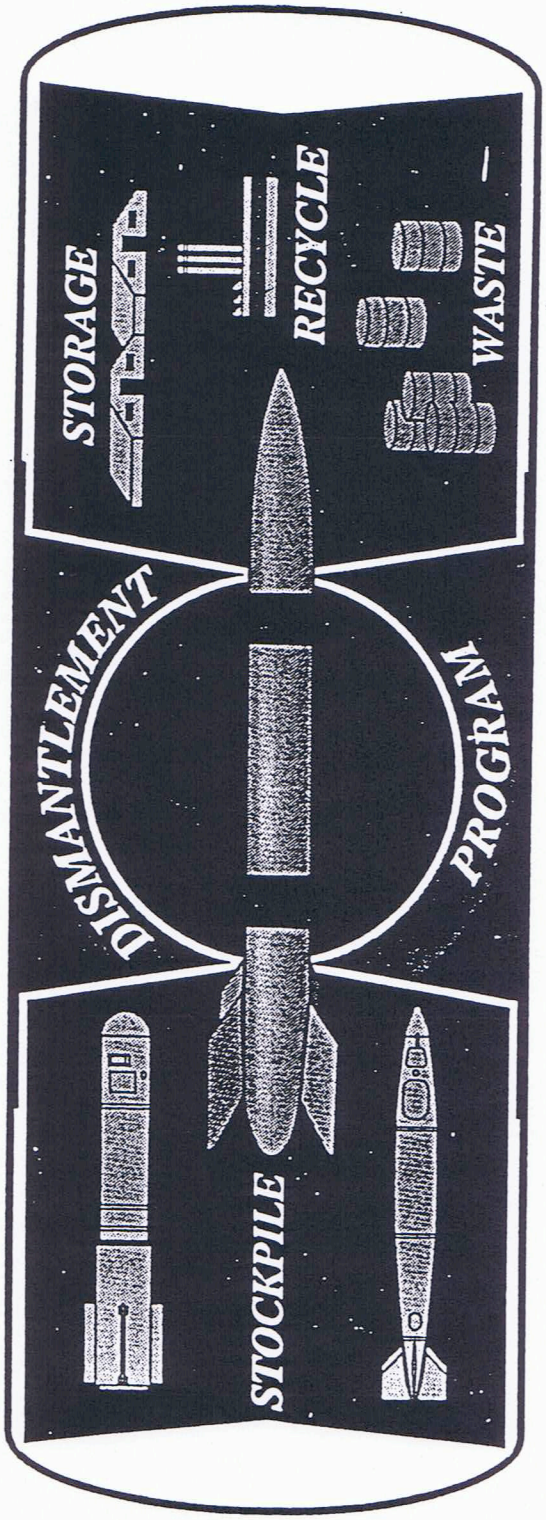


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PANTEX PLANT LOCATION

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Pantex Organization Responsibilities

- Government owned facility
- DOE Amarillo Area Office (reports to AL)
  - Administers operating contract
- Mason & Hanger - Silas Mason Co., Inc.
  - Management and operating (M&O) contractor
- Battelle Memorial Institute
  - Subcontractor for Environment, Safety, and Health (ES&H)
- Sandia National Laboratories
  - Operates Weapons Evaluation Test Laboratory (WETL)

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Pantex Plant Statistics

- $190M operating budget
- 2945 employees
  - 2600 M&H
  - 250 Battelle
  - 78 AAO
  - 17 Sandia
- 16,000 acres
- 2.5M sq. ft. buildings (425 units)

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Size of Dismantlement

- Pantex capability approximately 2000 per year
- Backlog of weapons
- Retirements continue
- [redacted]
- Taper off to support retirements as they occur

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Stockpile (P&PD 93-2)

SRD Viewgraph

Shows
Stockple, Reserves, and Retiring

(Not included herein)

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Department of Energy
Executive Mangement Team for Dismantlement

- Formed by DASMA
- Covers all aspects of retirement, return, disassembly, waste characterization, and disposal
- Develop integrated departmental positions and strategies for dismantlement
  - Internal to DOE
  - With DoD
- Membership with DoD
  - DOE/AL, DOE/HQ, LANL, SNL, LLNL
  - Reports to DASMA weapons panel

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Department of Energy
Executive Management for Dismantlement

DOE/AL	Deborah Monette	Chair
DOE/HQ	Karen Lombardo	Exec Sec
LANL	Mike Kelly	
LLNL	Jerry Dow	
SNL	Paul Longmire	

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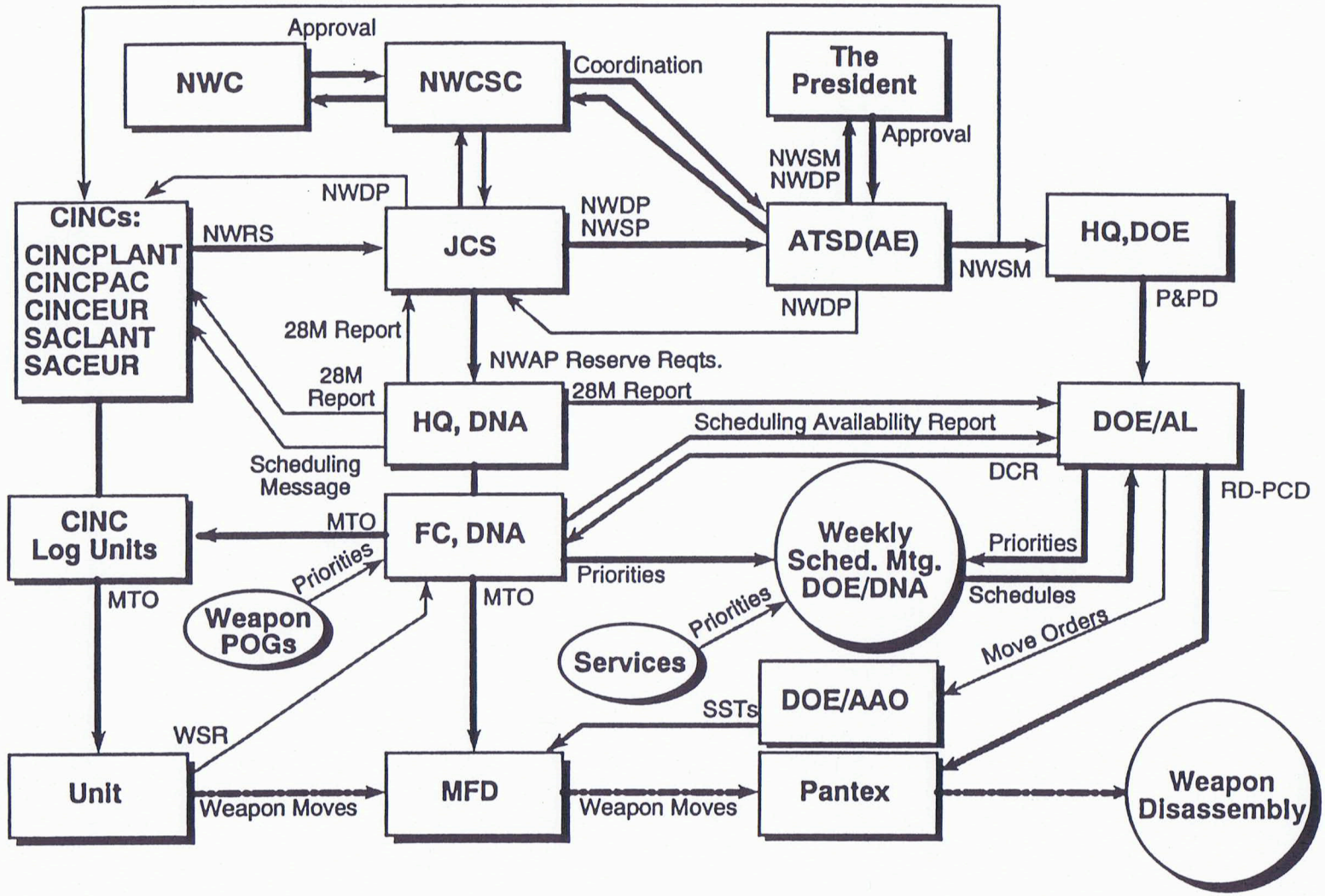
Dismantlement Priorities

- Weapons Shipment Planning
  - Priority based on risk analysis
- Material Destination - Disposal
  - Identification
  - Characterization
  - Obey Laws
- Storage of SNM
  - Keep at Pantex until better solution found

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DISMANTLEMENT PRIORITIZATION PROCESS



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Dismantlement Prioritization Working Group

- Joint DOE/DoD group chaired by Sandia
- Initial phase identified and ranked weapons based on weapon features
- Dismantlement process from initial retirements to disposal was defined
- Influences that determine priorities were identified
- DOE issues such as staging requirements and transportation assets were examined
- Software written to process data
- Group continues for information exchange and planning assistance

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b(3)

Information Systems

- Developing database for material identification and characterization
- Compatible with each DOE design agency and production agency
- Allows Pantex to receive information electronically
- Allows each DA and PA to enter their desired data
- Replaces old scrapbook system at Pantex

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DOE Dismantlement Policy
Component Retention, Reuse, or Evaluation

- For each weapon in the dismantlement process, a laboratory study will be conducted to determine if any of the major assemblies, components, or their subcomponents should be:
  - (1) Retained for reuse
  - (2) Salvaged for their strategic or economic value
  - (3) Retained for safety and use-control effectiveness evaluations
  - (4) Evaluated to provide further statistical data regarding the quality and reliability of comparable hardware in the enduring stockpile

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Non-Nuclear Hardware From Dismantled Weapons

- All hardware scheduled for disposal unless otherwise requested
- Sandia plans to request designated hardware to be returned for evaluation
- Possible storage of Sandia hardware for future use when a direct replacement in the enduring stockpile, e.g., mods of B61
- Los Alamos plans no storage of hardware except for Detonators
- LLNL plans no storage of hardware
- Evaluation units for LANL and LLNL will be requested as needed

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Component Commonality Matrix, A Few Examples

Dismantled Weapons	Enduring Stockpile			
	B61	W78	B83	W76,W80,W87,W80
B57	Solder Conn		Para chute	
W68	Trig Ckt	Trig Ckt	Trig Ckt	
W70	LAC	LAC N.G.	LAC	

W56, B61-0, W69, W71, W79

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DOE Dismantlement Policy
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DSD Manual

The Demilitarization and Sanitization for Disposition (DSD) Manual defines the process to be utilized in the nuclear weapons complex for applying the general guidelines to define and document a demilitarization, sanitization, and/or render-safe process. The process description covers the use of the Demilitarization/Sanitization Table, the Weapon Component Data Sheets, and the issue resolution process.

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MMSC Demilitarization/Sanitization

Part Nomenclature	*Demilitarization*	*Sanitization*	*Render Safe*	*Method*
Actuators/Squibs	Yes	No/Yes	Yes	Fire or explosive disposal (some use control items may require sanitization)
Connectors	No	No/Yes	No	None (unless rad hardening potting used, then sanitization required)
Detonators and Cable Assemblies	Yes	Yes	Yes	Fire - shred cable/crush header or explosive disposal (protect# info.)
Foams, cushions compression pads, desiccants, plastics, etc.	No	No/Yes	No	None (shred, melt, or burn if show classified contours or shock mitigation info.)
Mechanical Hardware (O-rings, brackets, bolts, cover plates, rings, etc.	No	No	No	None (part identifier removed if association makes classified)
Neutron Generator, Electronic	Yes	Yes	Yes	Crush (remove rad tube?)
Neutron Generator, Explosive	Yes	Yes	Yes	Fire (mixed waste) or timer driver to explosive disposal/tube to rad waste
Reservoir	Yes	Yes	Yes	Bury (remove rad material if appropriate)
Thermal Battery	Yes	No	Yes	Fire
Timers	No	No	No/Yes	None (fire - remove explosives if appropriate)
Use Control, PAL, CD Hardware	Yes	Yes	Yes	Expend, crush, shred, bury as appropriate

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Nuclear Material Storage/Disposal

- All pits put in interim storage
  - Yet to determine ultimate fate of plutonium
- Secondaries under study
  - Portion to be stored
  - Portion to be disassembled into basic materials

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SNM Storage Problem

- Present Storage Magazines
  - Containers stored vertically in planar array
  - At present rate magazines full in March 1994
- Proposed Changes
  - Containers stored horizontally in multi-layers
  - Activate additional magazines
  - Problem Created
    - High radiation levels
    - Worker could receive yearly allowable dose in approximately one day
- Solution
  - Use machines to load, retrieve, and inventory

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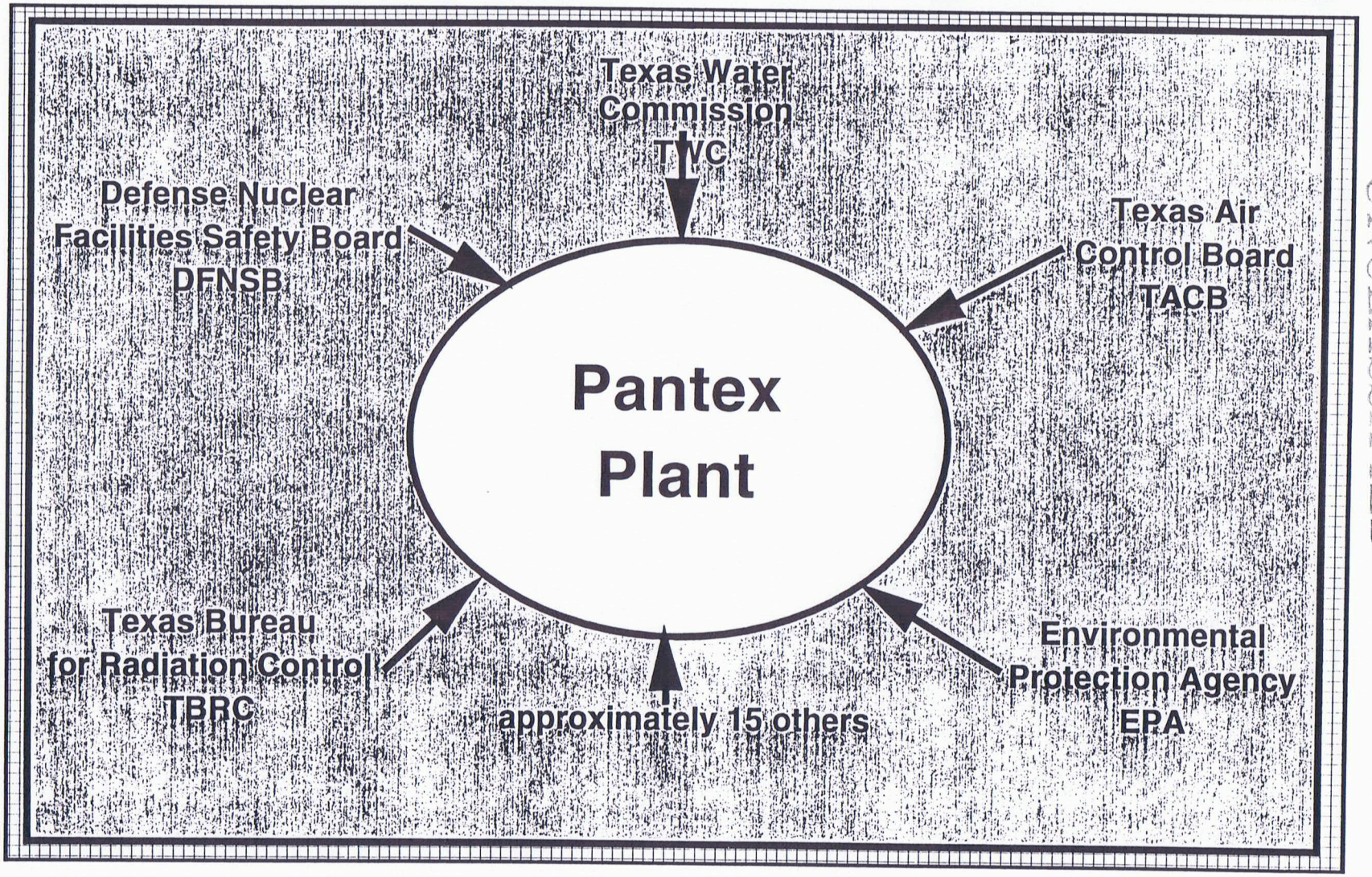
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Project Stage Right Storage

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External Oversight



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Sandia/Pantex Robotics

- Weighing and Leak Checking System (WALS)
- Disassembly
- System Studies

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Quality Evaluation for Dismantlement (QED)

- Concept originated in DOE Policy
  - Generated by EMTD and approved by DP-20
- Labs assess dismantlement process
- Level 1-Weapon receipt through disassembly
- Level 2-Subassembly and component preparation for disposal
- Joint Lab team effort to provide the best technical advice
- M&H-Battelle retains overall responsibility
- Defense Nuclear Facility Safety Board values to process
- Level 1 evaluations performed on W48, B57, W68, and W70
- Official Laboratory Quality Releases in December 1992
- Planning for Level 2 underway

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Lead Lab Approach

- Preserve technology at Laboratories
- Utilize limited resources supporting process and manufacturing development
- Maintain Laboratories' unique technical competence
- Enhance Laboratories' capability to provide limited backup
- Facilitate further enhancement of technology transfer
- Increases scope of Laboratories' functions and responsibilities
- Role and relationships of Labs and Production agencies will change
- Lead Lab responsible for maintaining technical excellence in production technology
  —"Cradle to grave"

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Pantex Lead Lab Assignments

- Weapon assembly/disassembly
  - Sandia, Paul Longmire
  - Nuclear subassembly
    - Los Alamos, Luis Salazar
- High Explosives
  - LLNL, Dick Hatfield
- Responsible for developing and certifying processes at plants for Complex 21
- Follow-on to Technology Assessment and Selection Panel (TASP)--currently in operation

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Tri-Lab Project Office

- 10/92 letter from Bruce Twining, MGR DOE/AL

"Laboratories play a stronger, more direct role, and well-defined role in nuclear operations, wherever they occur, with a first-step emphasis on Pantex operation"

"Establish a Joint Laboratory Technical Support Office"

- Tri-Lab Project Office in operation
  - Ribbon cutting ceremony Sept. 29, 1993
  - Four offices for each Lab
  - Three on-site residents from LLNL--Two from LANL
  - One resident from SNL--one more in process
- Full office facilities, e.g,, adm. support, repository

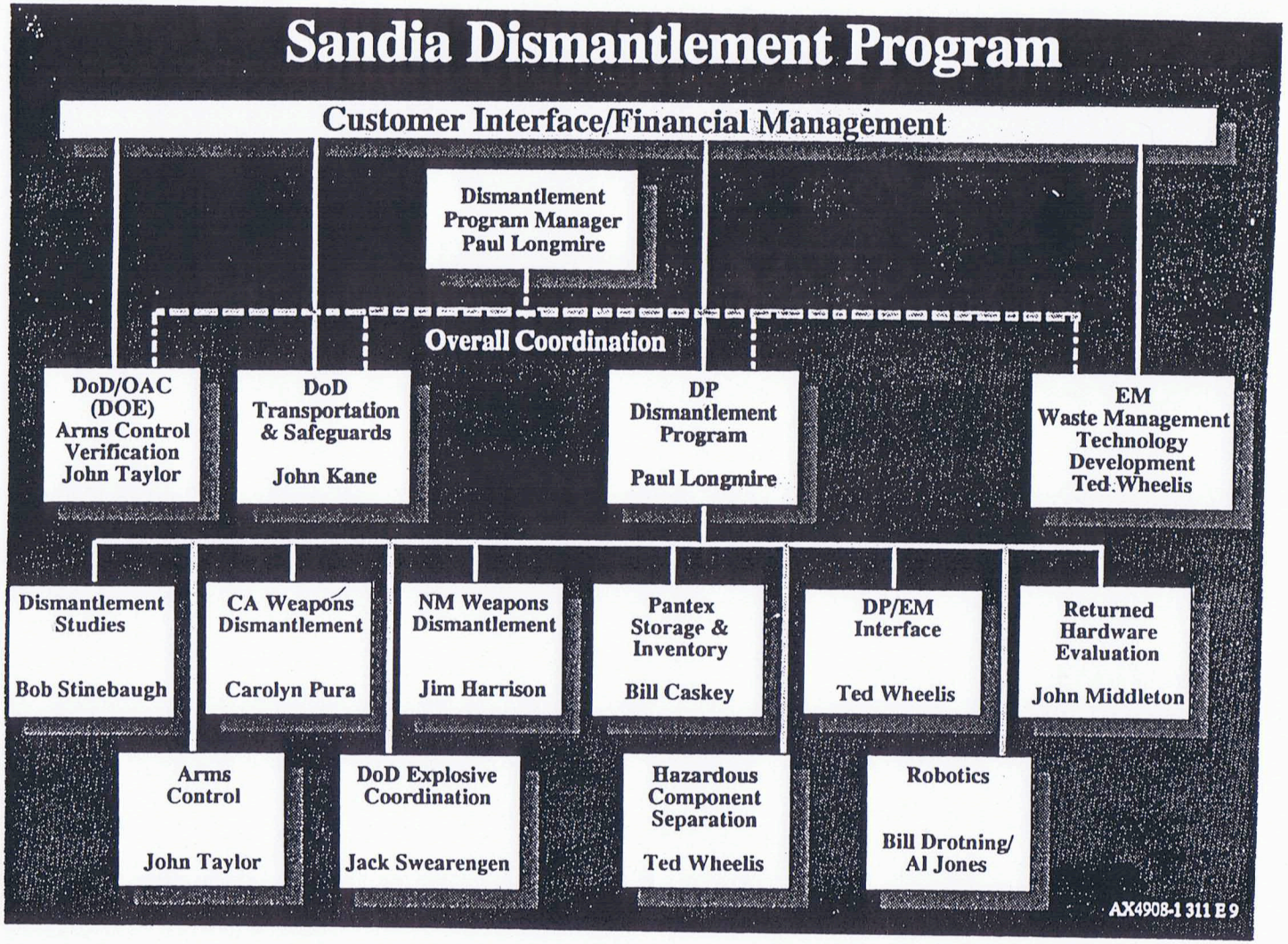
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Coopertive Program between US and Russian Labs

- Participants
  - US--Sandia, Los Alamos, and LLNL
  - Russia--Chelyabinsk and Arzamas-16
- Unclassified, non-sensitive information exhanges
- Four areas of activity
  - Risk assessment--Stan Spray
  - Transportation Surety--John Kane
  - Hazardous Materials--Paul Longmire
  - Communication and Translation--Patricia Newman
  - Hazardous materials includes handling, material ID, and waste management

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

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SESSION XI

- DETONATORS
- FIRING SYSTEMS
- NEUTRONS INITIATION
- POWER SUPPLIES

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Topics to be discussed

- Review of implosion assembly (IA) operation
- Review of stockpile detonators
- Firing system components
- Operation of explosive firing sets
- Stockpile firing sets
- Nuclear safety
- Production
- Future systems

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Assumptions for briefing

- Students have an undergraduate background in engineering or science

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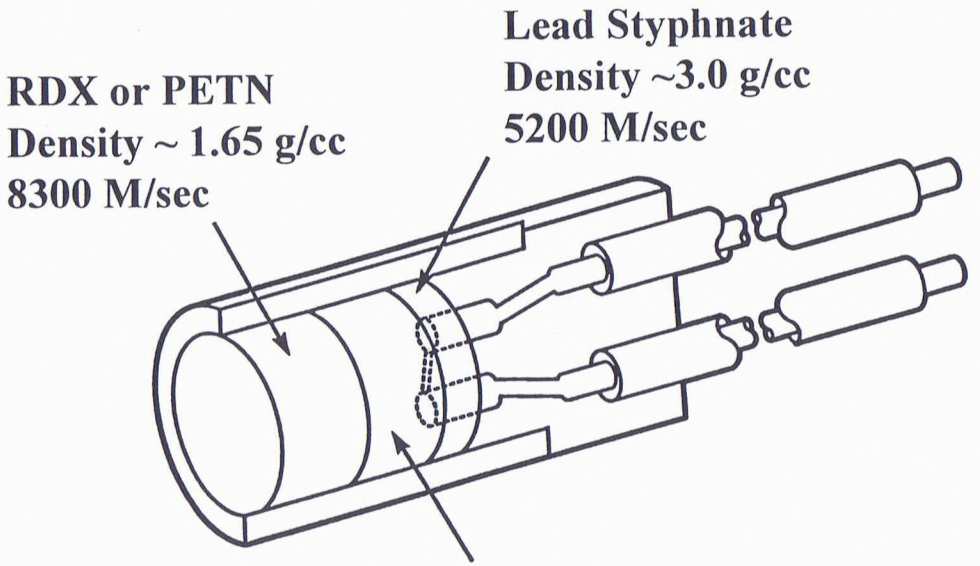
Basics of an Implosion Assembly (IA)

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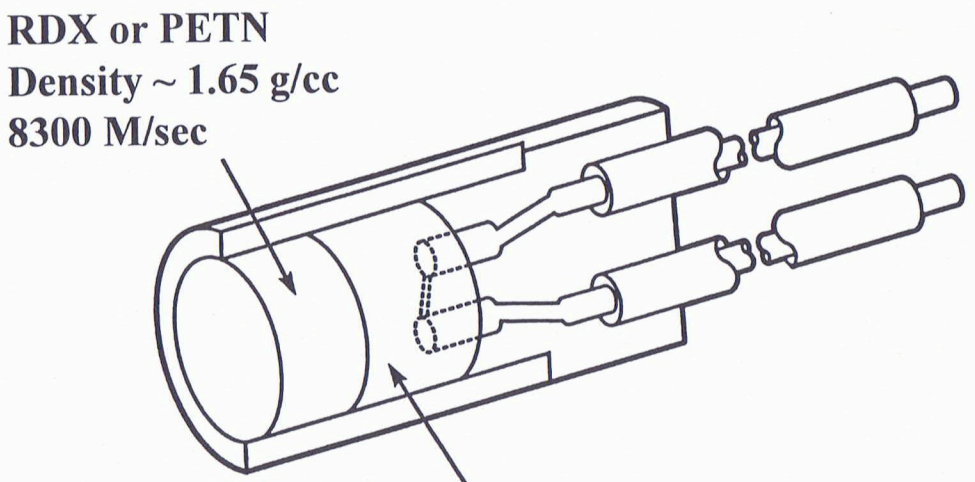
Typical hot wire detonator (Firing current ~ 5 amps)



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An exploding bridgewire (EBW) detonator (1.5 X 40 mil gold) initiation requires ~ 300 amps

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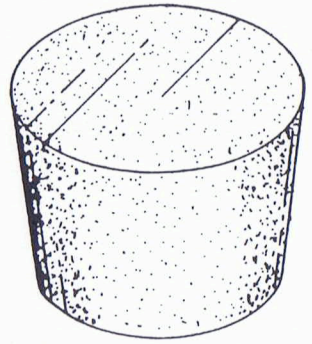


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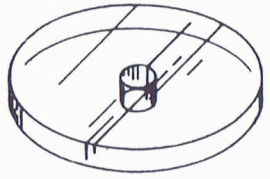
A basic exploding foil initiator (EFI), slapper detonator, consists of three components

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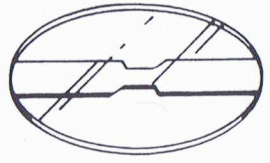
Secondary Explosive Pellet
(Typically HNS IV)



Insulating disk with
barrel (hole)



Etched metal foil
with insulated flyer



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The Mechanical Safe and Arm Device (MSAD) controls the detonator pellet in the W84 and W87

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EBW and EFI comparison for detonators which requires approximately the same initiation energy

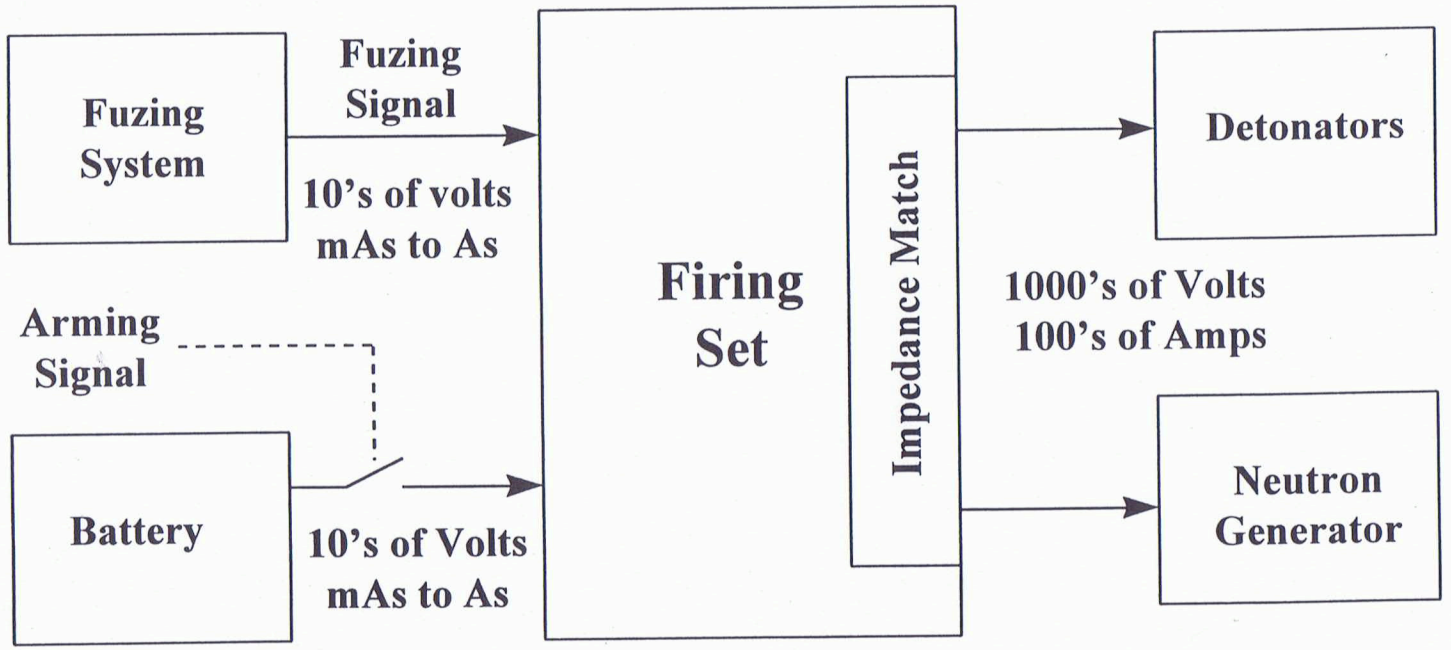
	Exploding Bridge Wire	Exploding Foil Initiator
Energy	250 mJ	250 mJ
Current	1000 Amps	2,500 Amps
Function time	2.0 μs	0.5 μs
Energy coupled into explosive	~ 20 % of stored energy	~ 5 % of stored energy
Explosive	PETN (0.8 gm/cc)	HNS (1.6 gm/cc)
HE melting point	140° C (100° C degrades)	320° C (doesn't degrade)

* EBWs need recovery; slappers don't.
* Slappers are more environmentally rugged.

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Firing set provides: 1) Low to high voltage/current conversion; 2) Fuze/Fire interface; & 3) Det/NG interface

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{Arming, Fuzing and Firing (AF&F)}

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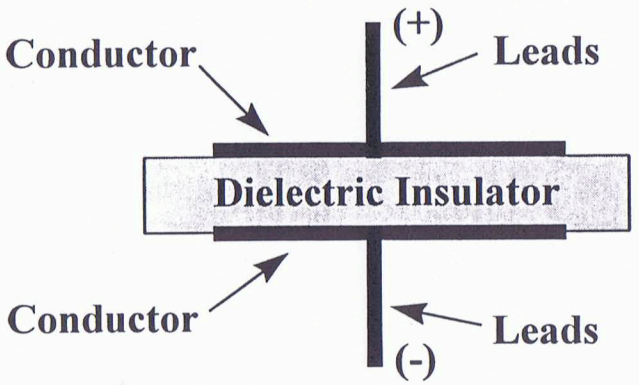
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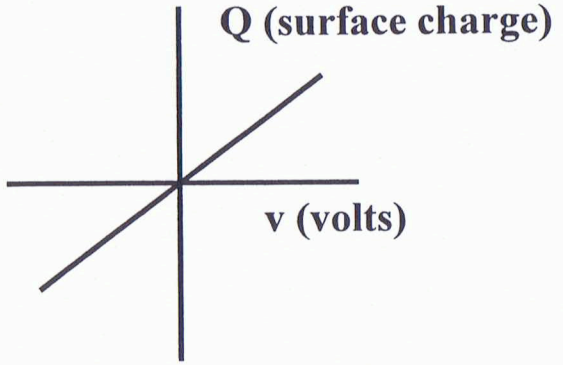
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What is a capacitor? Basically two conductors seperated by a dielectric

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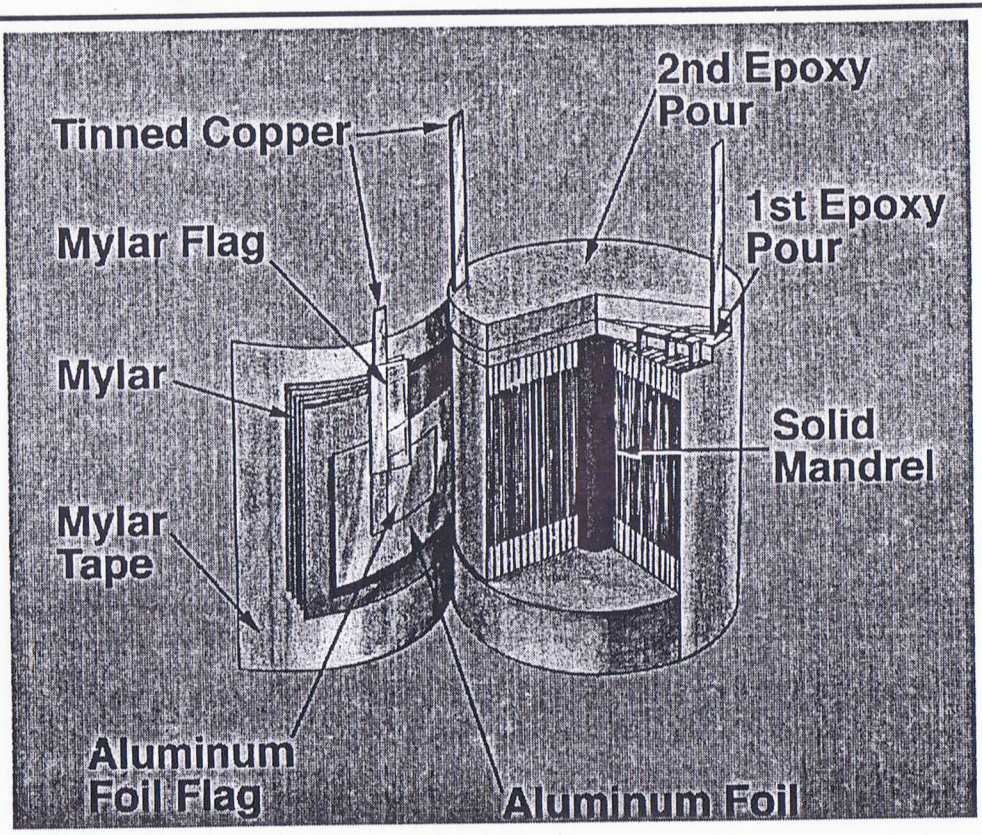
$$\text{Energy} = 1/2\ CV^2 = 1/2\frac{Q^2}{C}$$

- Q is the charge in coulombs
- C is the capacitance in farads
- V is the potential in volts

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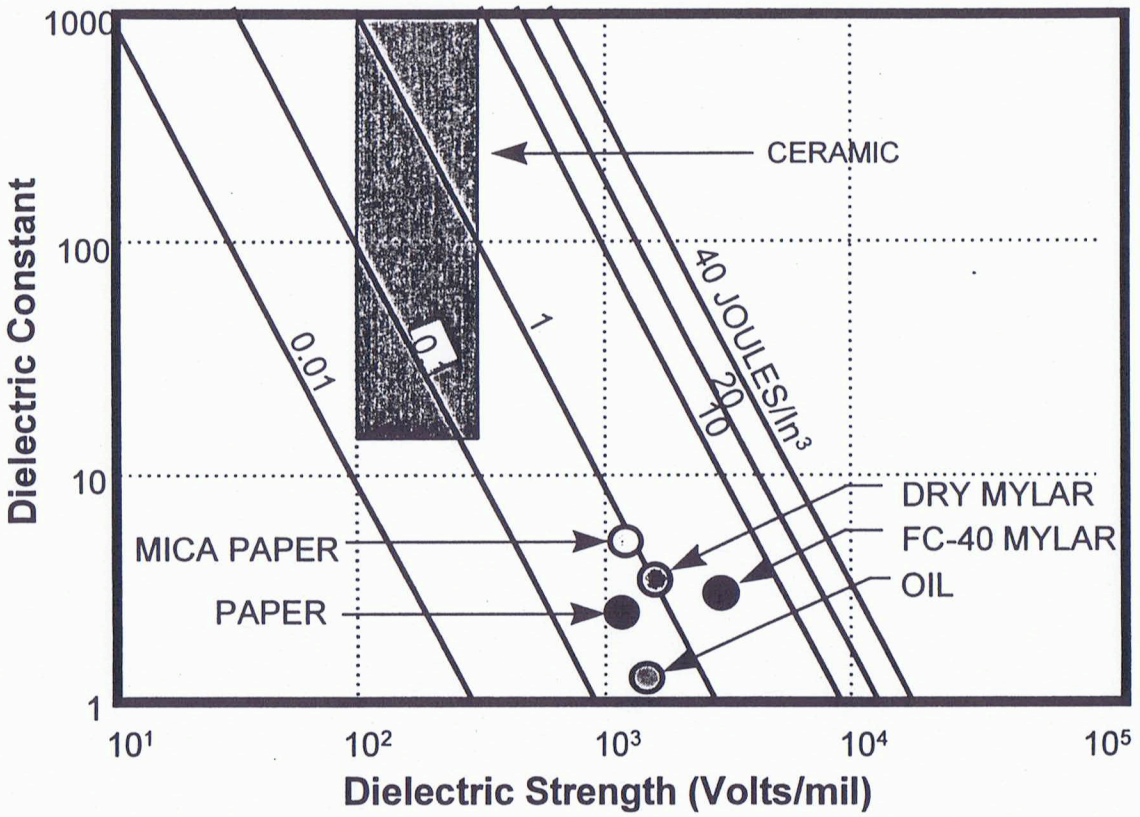
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High voltage firing set capacitor (High Energy Density (HED) capacitor)



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Tradeoff of dielectric strength and dielectric constant - at field use condition



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Firing set capacitor bank for a large number of detonators

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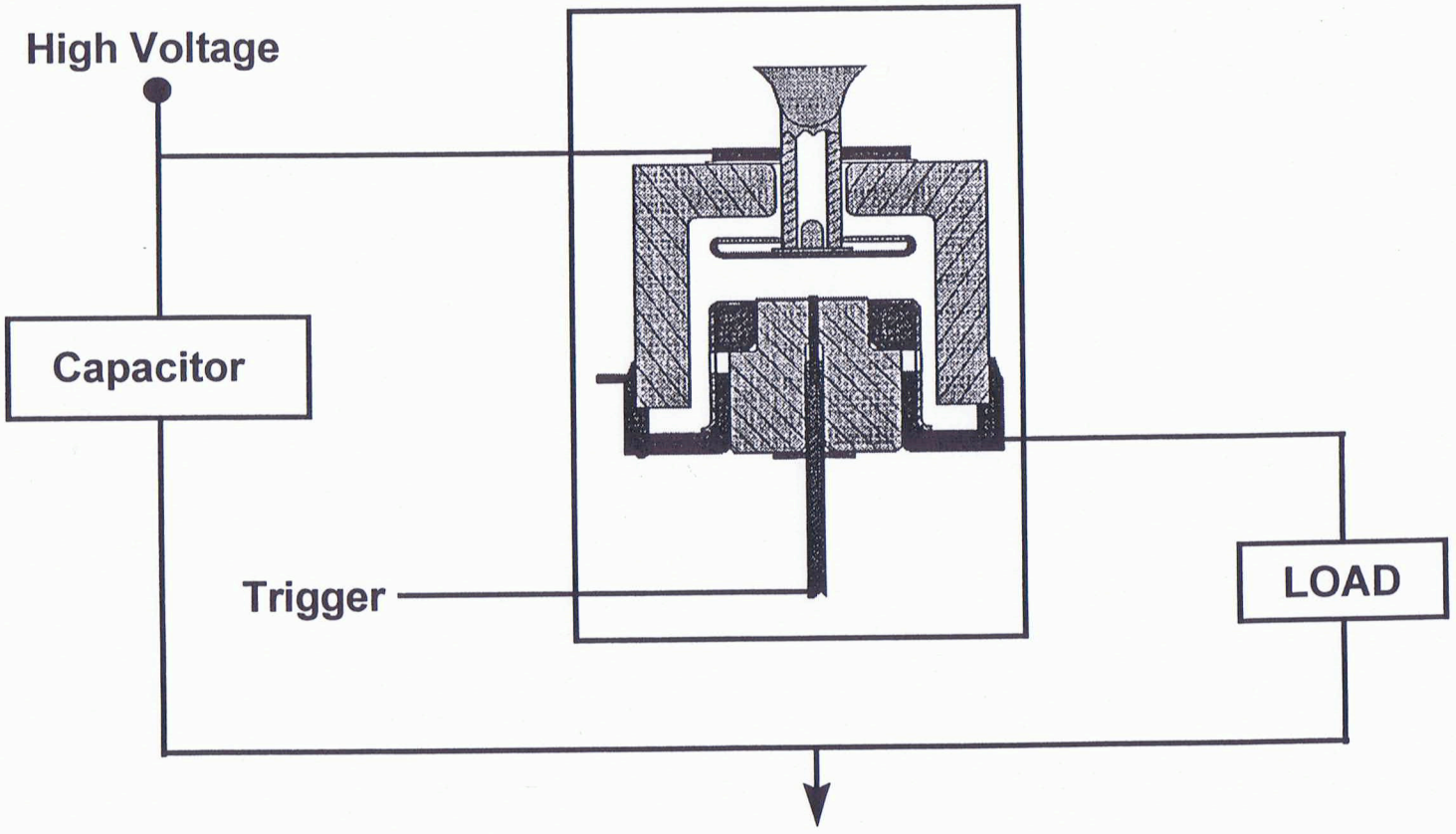
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Examples of high energy density capacitors

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Basic operation of a switch tube



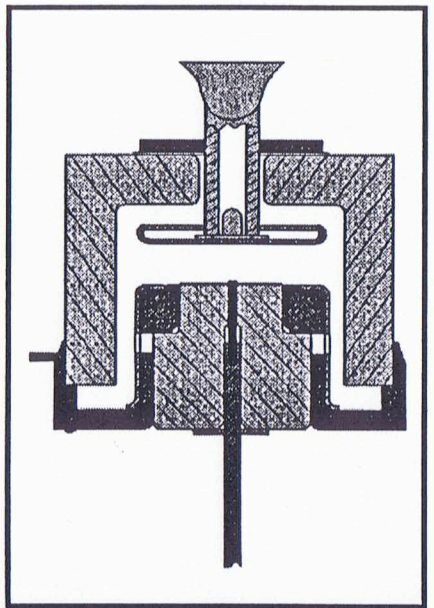
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Vacuum and gas switches

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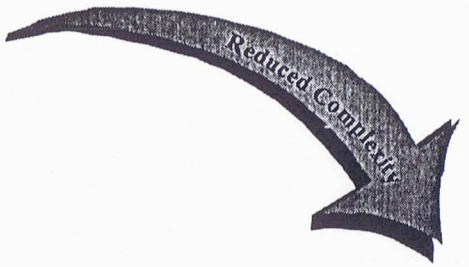
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Technology shift has led to reduced complexity and more repeatable processes

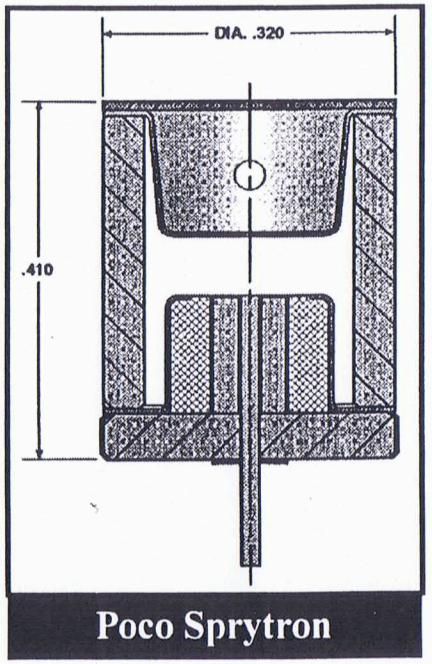


Typical Sprytron

1. Fab/Test Cycle Time ~ 2-4 months
2. Unit Cost ~ $2-3K
3. Facility Space ~ 65,000 sq. ft.
4. Facility Cost ~ $5M
5. Multiple operations to closure



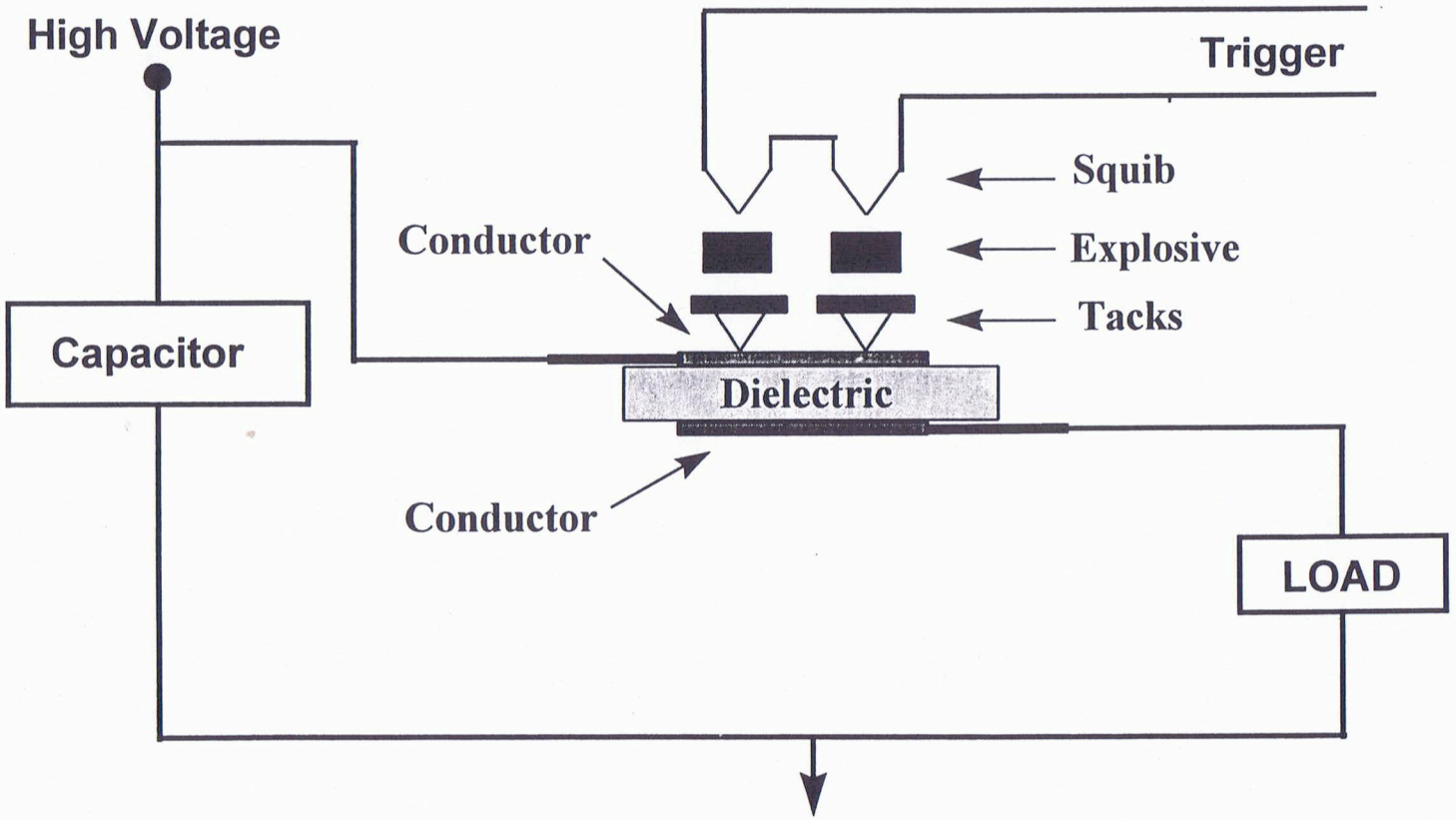
1. Fab/Test Cycle Time ~ 2-4 weeks
2. Unit Cost ~ $200-400
3. Facility Space ~ 5,000 sq. ft.
4. Facility Cost ~ $1M
5. Single Step closure



Poco Sprytron

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Explosive tack switch system - (Solid dielectric switch (SDS), Explosively driven switch)



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There are two technology areas that have been employed in the stockpile

- Capacitor Discharge Unit (CDU) Firing Set
  - Typically all electric
  - Re-testable when it is all electric
- Explosive-to-Electric Transducers (EETs)
  - Chemical energy from explosives are used in the production of electrical energy
  - Single pulse or one shot device

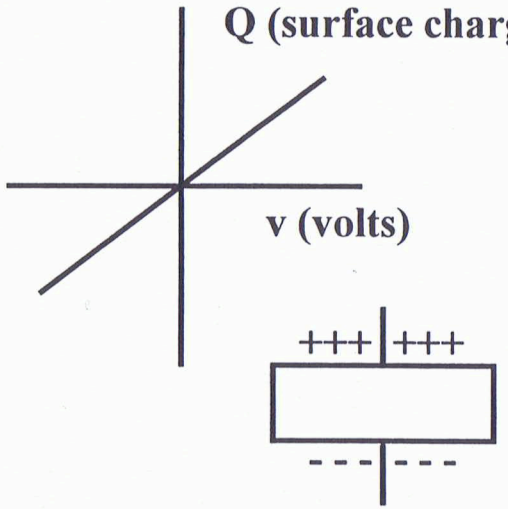
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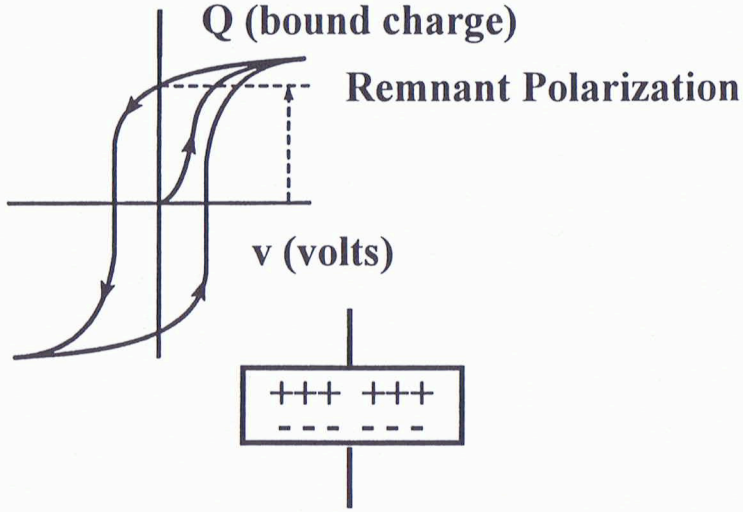
Ferroelectric (FE) material retains a bound charge like a capacitor retains a surface charge

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CDU



FE

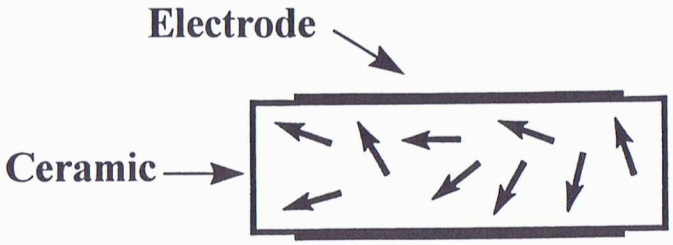


$$\text{Energy} = 1/2\ CV^2 = 1/2\frac{Q^2}{C}$$

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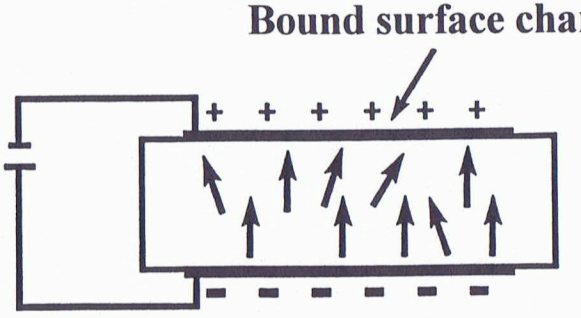
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Bound charges are formed in a ferroelectric (FE) material during poling process



Unpoled Ceramic

Polycrystaline multidomain ferroelectric ceramic

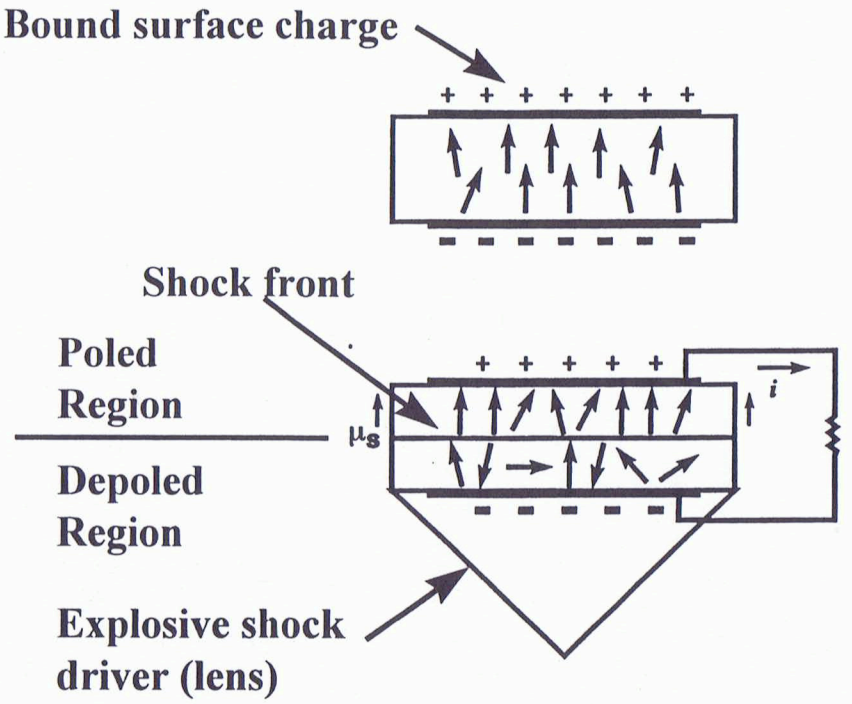


Polling Process

Domains aligned by impressing external electric field

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A shock wave of the correct magnitude releases bound charges in ferroelectric (FE) material



Poled Ceramic

Bound surface charge remains due to internal electric field

Shock Depoling Process

Shock wave randomizes dipoles elminating internal field, thus freeing bound charge to external circuit.

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Ferroelectric firing set

B54 and/or Isolator

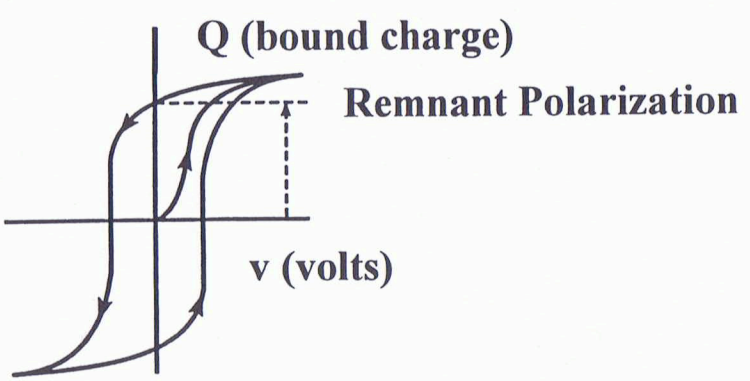
Define isolator and where it is used
and why it is used

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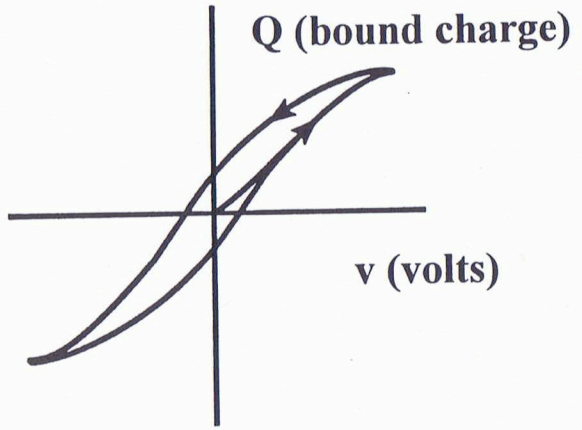
Slim Loop Ferroelectric (SFE) material reduces remnant polarization to fraction of a micro coulomb

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FE



SFE



$$\text{Energy} = 1/2\ CV^2 = 1/2\frac{Q^2}{C}$$

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MC3028 Firing set

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Firing set technology comparisons

Firing Set Technology	Typical Application	Relative Advantages	Relative Disadvantages
CDU	Bombs & Cruise missiles	Retestable no HE	Special effort to Harden
FE	Isolators	Power source not required, small, inherently rad hard	HE required Stored energy
SFE	Missiles (RBs, RVs)	Small, inherently rad hard	HE required Requires trigger
FM	Artillery shells (AFAPs)	Fastest arm/disarm Small, rad hard	HE required
CMF	Under ground testing (UGT)	Large output current & energy, rad hard	Long function time, HE required, requires timed trigger

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Firing sets have many complex requirements beyond that of initiating detonators

- Firing set complexity may be driven by
  - Nuclear safety
  - Radiation
  - Use control
  - Housing/mounting for other components
  - Testability
  - Manufacturability
  - Cost
- There may not be syngerism between requirements

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Nuclear safety requirements require the implementation of several complex features

Principles	Implementation
Isolation	Barriers, Strong links
Inoperability	Weak links, Colocation
Incompatibility	Unique signal operated devices
Independence	Multiple independent safety subsystems

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Firing system with enhanced nuclear detonation system (ENDS) features

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Capacitor technology - tradeoff of thermal weak link properties and radiation properties

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Packaging of the printed wiring assembly (PWA) in the B83 firing set before "sylgard 184 GMB"

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Packaging of the printed wiring assembly (PWA) in the B83 firing set after "sylgard 184 GMB"

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Simple nuclear weapon firing set

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Firing systems in the active stockpile

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Firing sets and detonators in the active stockpile

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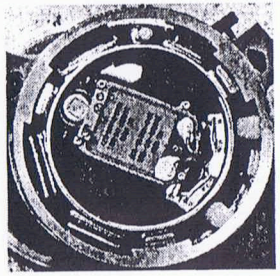
Firing set production is ongoing at a low level

Weapon	MC Number	Technology	Quantity
B83	MC3971A	CDU	~ 10/month ongoing
W87	MC3719	CDU	~ 3-4/month starting 1998

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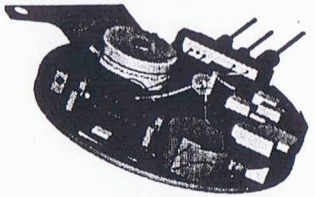
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Roadmap for Advanced Firing/Detonation Systems (AF/DS) supports future stockpile needs

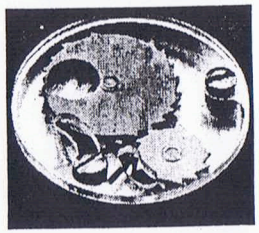


Stockpile Firing Systems

Increased Surety

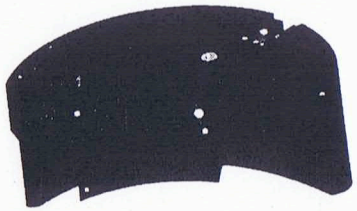


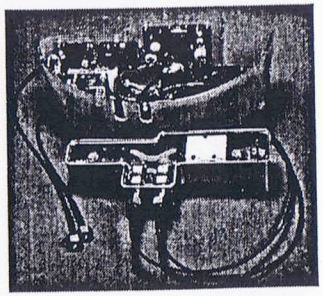
Micro-CDUs



Detonator Stronglinks

Miniaturization/
Increased System
Functionality





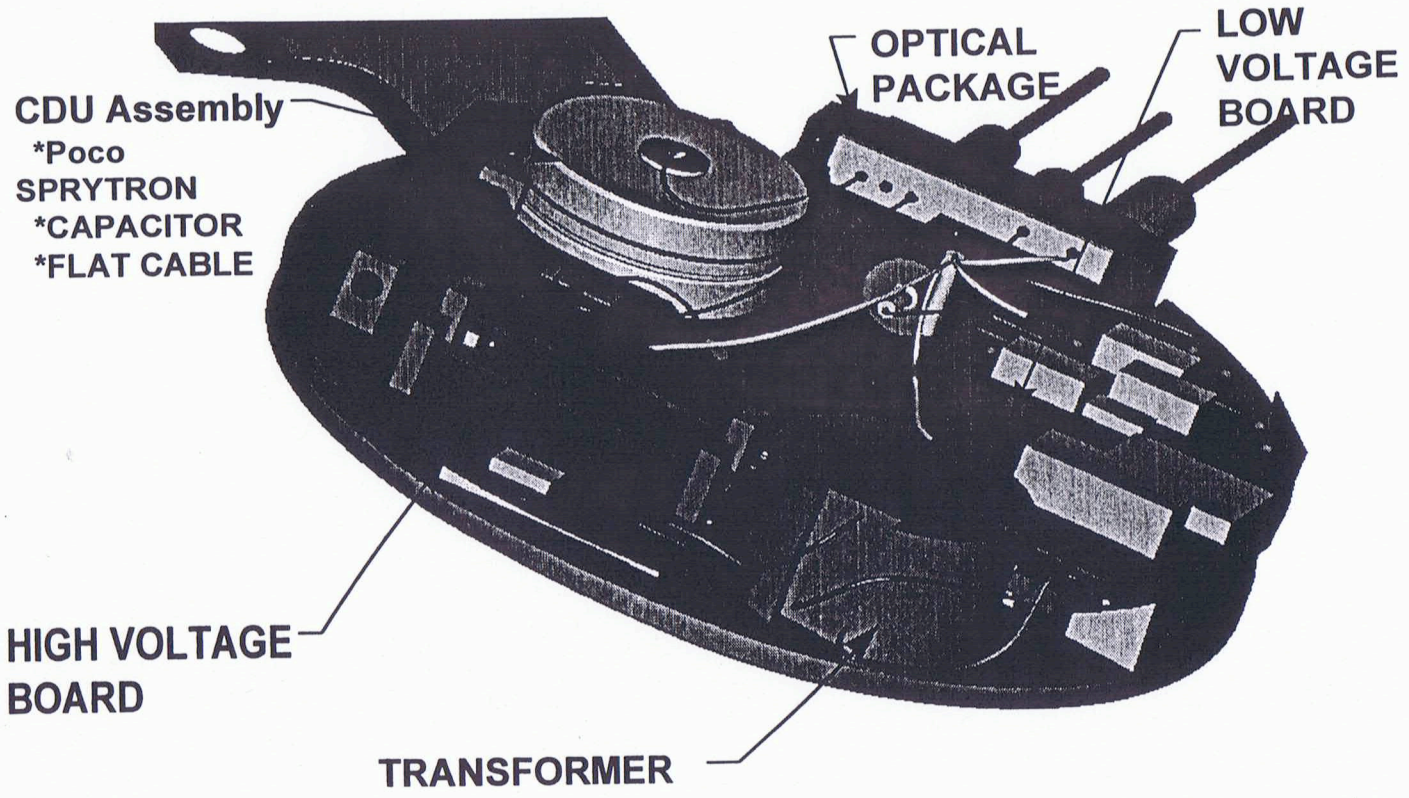
Direct Optical Initiation

Present → Future

Support Stockpile Life Extension Program

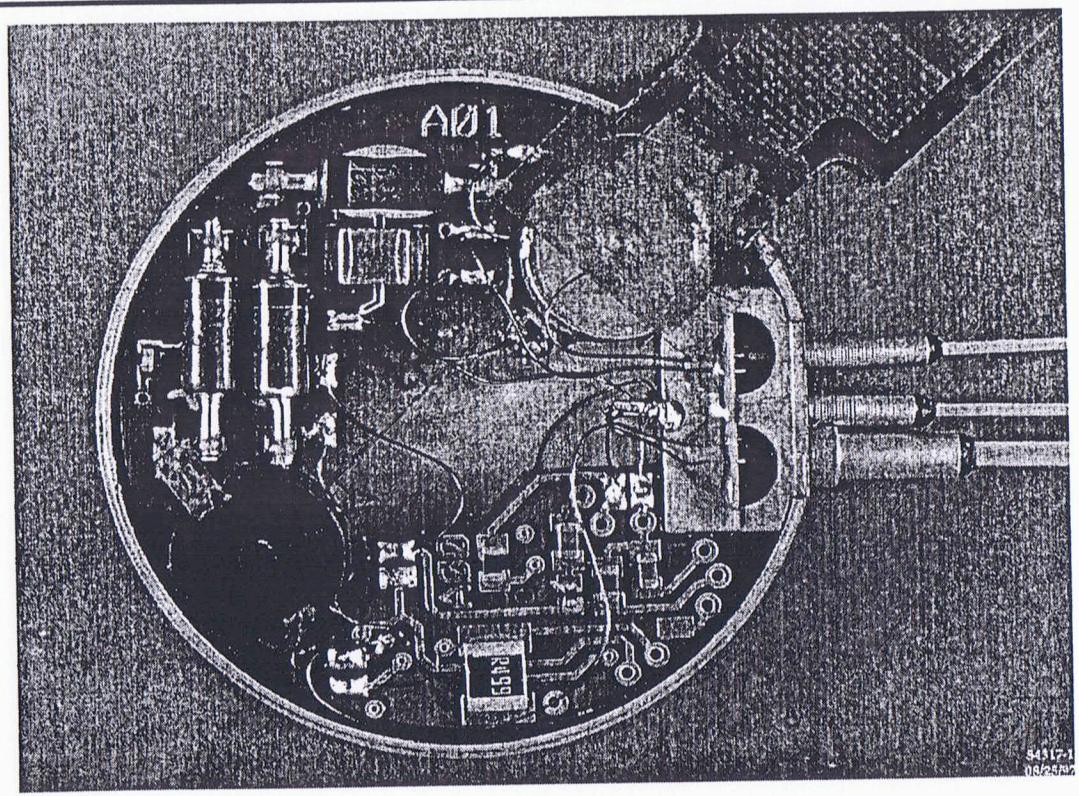
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Micro firing set



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Micro CDU firing set working prototype



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Micro CDU - 0.23 in^3 - Working prototype

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Neutron Initiators
Topics to be discussed

- Internal initiators
- External initiators
- Movie - An overview of neutron source technology
- Technology involved
- Evolution of neutron generator development
- Production
- Future systems

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Basics of an Implosion Assembly (IA)

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Neutron yield is dependent on ion source material and ion energy

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Neutron multiplication rate

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There are two fundamental reasons neutron sources are used in weapons

- Jump start the weapon
- Stabilizes the output

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Alpha curve

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Show Movie

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Basics of how a neutron tube work

Picture of a neutron tube

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Neutron generator using an explosive to electric (EET) power supply

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Neutron generator using an electronic power supply

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Implosion Assembly (IA) timing requirements

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Neutron generations requirements over time

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Neutron generator timing is affected by several factors

- System center time shift with temperature
- Neutron generator center time shift with temperature
- Neutron generator jitter
- Firing set jitter
- Weapon detonator jitter
- Neutron generator detonator jitter (explosive NG)
- Shift in electronic components (electronic NG)

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Neutron generator "family" picture

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SNL is now the production agency for neutron generators

- The targets will be loaded at LANL
- The first production requirement is for the W76 (2000)
  - MC4277 Neutron Tube
  - MC4380 Neutron Generator
- Future need for a small tube/generator for W80
  - FY2008? (P&PD 96-0)
  - Requires the small neutron tube, MC4300
  - MC4600 neutron generator

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MC4380 Neutron generator

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MC4300 Neutron Tube

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Design evolution from the MC4300 neutron tube (W76) to the MC4600 neutron tube (future applications)

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Power Systems

- Basic battery types
- Examples of non thermal batteries
- Thermal battery applications
- Thermal battery operation
- Examples of thermal batteries
- Power supply design influences
- Battery performance
- Evolution of Battery Development
- Production
- Future Technology

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Basic battery types

- Primary: not rechargeable
  - Active: power immediately available
  - Reserve: must be activated
- Secondary: rechargeable
- Nearly all nuclear weapon batteries are primary batteries
- Most weapon batteries are reserve batteries

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Types of power sources in nuclear weapons

- Thermally activated
- Rechargeable - Ni/Cd
- Reserve - Zn/AgO
- Active - Li/SO_2
- Active and reserve - Li/$SOCL_2$
- RTG (fissionable heat source)
  - Radio isotropic Thermal electric Generator (RTG)
- Double-layer capacitor

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Non thermal battery applications

- SA2039

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Picture of a generic thermal battery

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Picture of thermal battery cell

- Current
- Voltage
- Anode, cathode, electrolite
- Thermal vs current handling requirements

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Thermal batteries are used in many nuclear weapon applications

- RADARs
- Programmers
- Timer
- Firing sets
- Spin rocked motors
- Parachute deployment
- Telemetry
- Command disable
- Command enable
- Fin activation

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What is a thermal battery?

- Thermal batteries are primary reserve batteries that employ inorganic salt electrolytes, which are nonconductive solids at ambient temperatures, and integral pyrotechnic materials scaled to supply sufficient thermal energy to melt the electrolyte.

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Movie

- **Thermal Battery Ignition**

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Thermal battery performance- voltage - with constant load

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Thermal battery performance- current - with constant load

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Calcium chromate performance

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Lithium battery performance

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Power supply design influences

- Reliability (0.995 - 0.997)
- Shelf life - Thermal battery > 25 years
- Ruggedness - W82 AFAP application
- Operating temperature
- Current density
- Pulse capability
- Voltage - determined by cell chemistry

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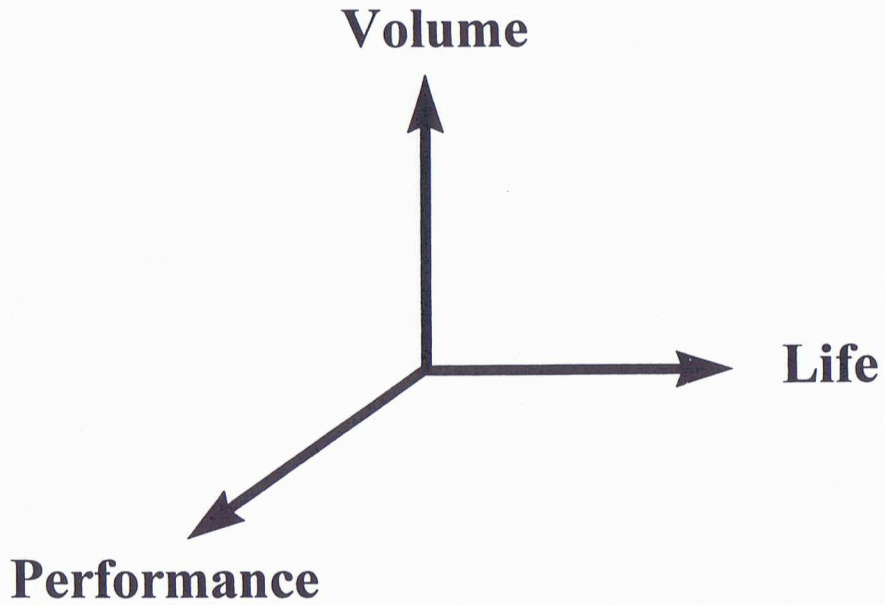
Thermal batteries are mechanically and environmentally robust

- Example of the W82 AFAP MC3714 environmental requirements
  - Spin: 18,000 rpm
  - Setback acceleration : 17,000 g's, 10 ms
  - Angular acceleration: 40,000 rad/sec^2
  - Ramming shock: 440 g, 1.83 ms, haversine
  - Rebound acceleration: 4000 g's 0.3 ms

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The three dimensional design space for batteries is volume, performance, and life

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Picture showing thermal battery performance versus size

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Typical thermal battery performance
Values based on Li(Si)/FeS_2 system

Battery Type	Active Life (sec)	Min Volts (v)	Current Density (mA/cm^2)	Specific Power (W/Kg)	Volume (cc)
Pulse	0.050	17.5	7500	8000	10
Pulse	5	26	1000	1700	10
Power	200	12	1800	740	1640
Power	60	25	300	260	137
Power	120	26	120	80	360
Power	1200	26	100	80	320
Long Life	4500	13	55	18	320

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Examples of batteries used in the US nuclear weapons program

Weapon	Technology	Cell Voltage	Approx. Date
Little Boy	Lead Acid	2.0 volts	1945
Fat Man	Lead Acid	2.0 volts	1945
MK4,5,6,7	Nickel-Cadium	1.2 volts	1953
MK15	Thermal CA-$CaCr0_4$	2.5 volts	1955
W62	Silver-Zinc	1.8 volts	1970
W70	Thermal Li/FeS_2	1.9 volts	1973
B83	Thermal Li/CoS_2	1.8 volts	1980's

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W76 thermal battery

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MC2936 thermal battery

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Battery production is currently taking place at three production agencies (PAs)

- Eagle Pitcher
  - The primary PA which resulted from the nonnuclear reconfiguration study
- SNL
  - The backup site for production which resulted from the nonnuclear reconfiguration study
- Enser Corporation - Private Corporation
  - Recently formed out of Martin Marietta Specialty Components, Inc. (GEND, Pinellas Plant)

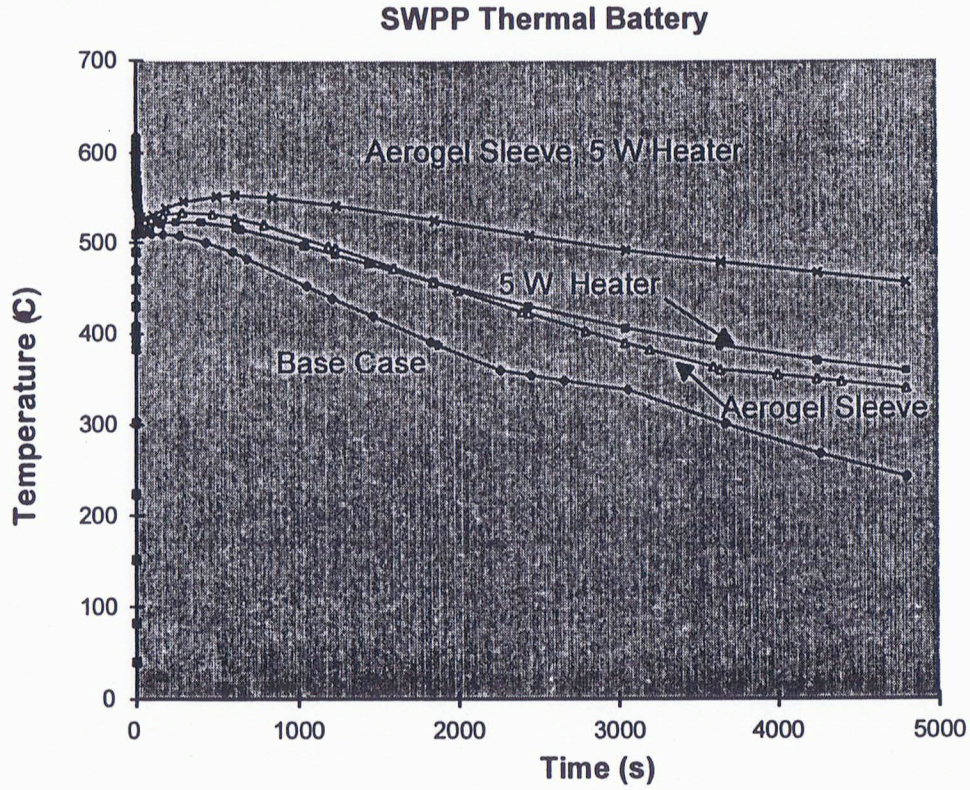
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Battery production is at a low level

Company	Nomenclature	Type	Application	Quantity
Eagle Pitcher	SA3562	Zn/AgO	JTA	~ 2 Dozen
	MC3471A	Thermal	B61	300-400
	MC2736A	Thermal	JTA	~ 2 Dozen
Enser	MC3323A	Thermal	W80 JTA	~ 2 Dozen
SNL	MC4152	Thermal	B61 Common JTA	~ 2 Dozen

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Aerogel and a heater may increase battery output without increasing volume



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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION XII

•NUCLEAR TESTING

PHYSICS PACKAGE DEVELOPMENT TOOLS

- THEORY
- NON-NUCLEAR TESTING
- NUCLEAR TESTING

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NON-NUCLEAR IMPLOSION DIAGNOSTICS

- PHERMEX (RADIOGRAPHY)
- PIN DOME
- HIGH SPEED PHOTOGRAPHY

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NUCLEAR TESTING

- WEAPON DEVELOPMENT
- EFFECTS
- VULNERABILITY AND HARDENING
- STOCKPILE RELIABILITY
- PEACEFUL NUCLEAR EXPLOSIVES

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DIAGNOSTICS

- YIELD
- "ALPHA"
- CHANNEL TEMPERATURES
- INTERSTAGE TIME
- OTHER

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REFERENCES

- LA2000 1947 SRD
- WT900 DEC 1953 SRD

FIREBALL YIELD

- SAND 77-0402 - "SHOCK PROPAGATION..." SLIPHER
- DNA-119M REPORT
- DASA 1211 - 1220 REPORTS
- LLNL RESEARCH MONTHLY 3141-83-1033 (DIAGNOSTICS)
- DNA 170M REPORTS
- LASL-LLL SPECIFIC TEST REPORTS

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY WR708

SESSION XIII

•TRANSFER SYSTEMS

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GAS TRANSFER SYSTEM TECHNOLOGY

STEVEN ROBINSON, 8412

COMPONENT DEVELOPMENT DEPARTMENT

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SANDIA GAS TRANSFER SYSTEMS

- Classification
- Introduction
- Examples
  - Systems
  - Reservoirs
  - Valves
- Concerns

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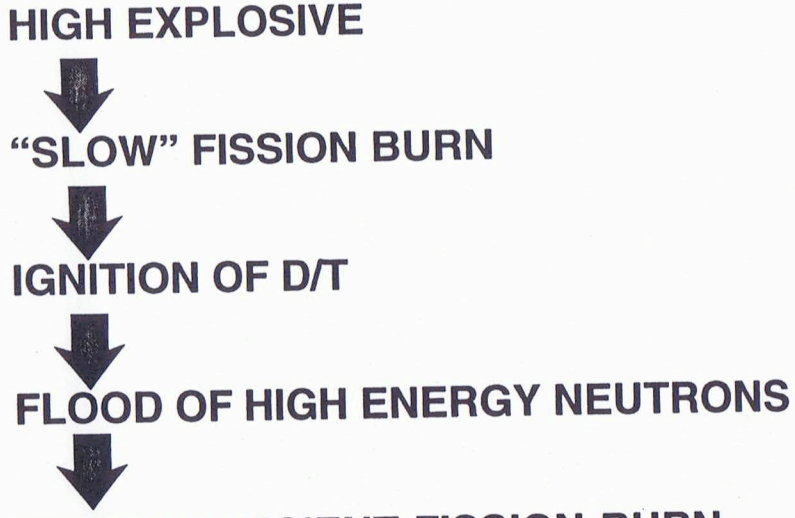
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BOOSTING

DEUTERIUM AND TRITIUM ARE USED TO MAKE PLUTONIUM BURN MORE EFFICIENTLY (I.E., TO "BOOST" THE FISSION YIELD).



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Tritium

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WEAPON BOOSTING REQUIRES THE ABILITY TO STORE MIXTURES OF HYDROGEN ISOTOPES AND TO DELIVER THE APPROPRIATE MIXTURE ON DEMAND

THIS REQUIRES

- Containment reservoirs
- Flow Systems
- Explosive Valves

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CHALLENGES WITH GAS TRANSFER SYSTEMS

- Long Term Degradation
- Constancy of Delivery
- Complex Plumbing
- Minimization of Weight and Volume
- Cost

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STOCKPILE LIFE, YEARS

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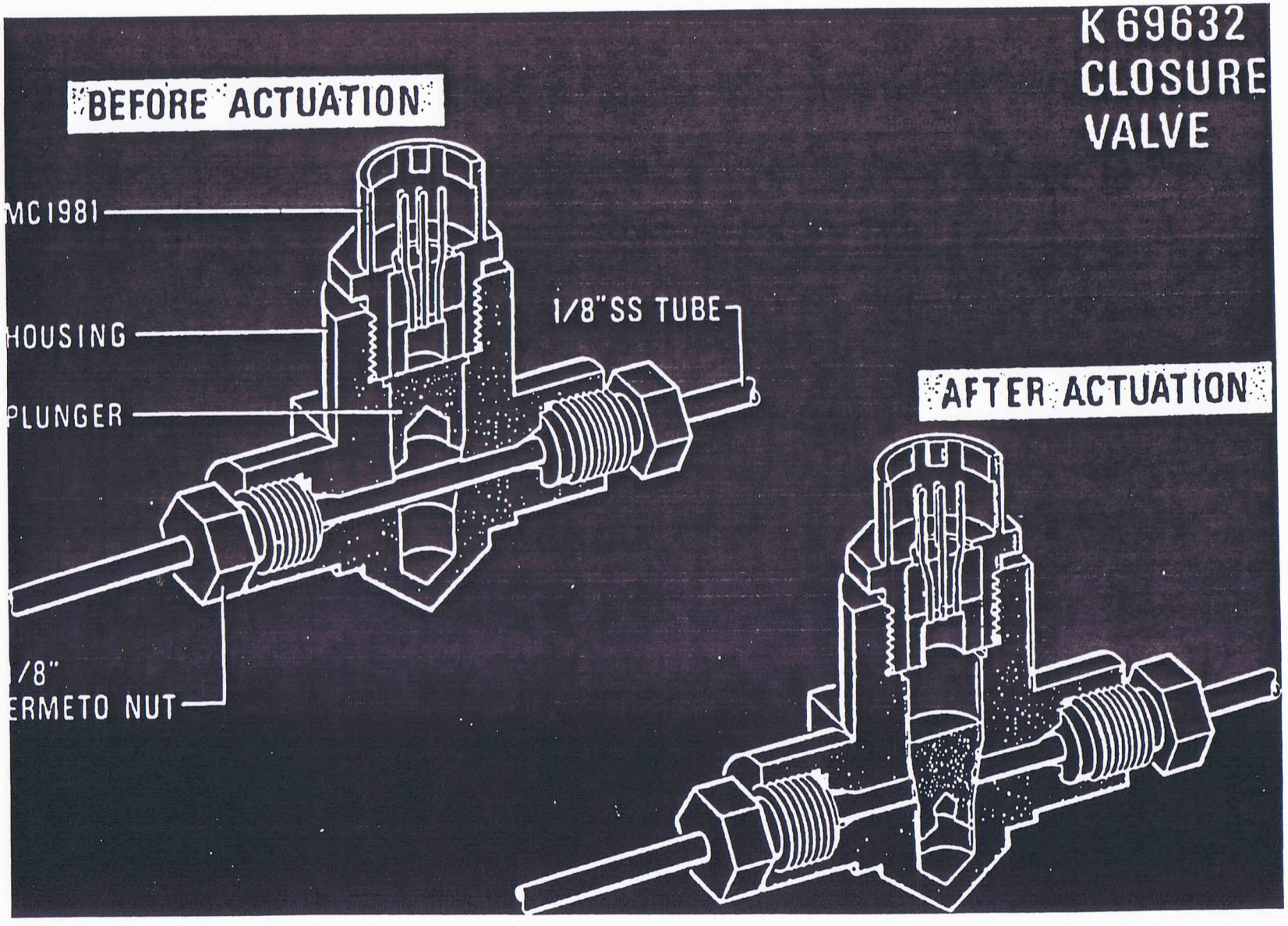
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BEFORE

AFTER

EXPLOSIVE VALVE OPERATIONAL SEQUENCE

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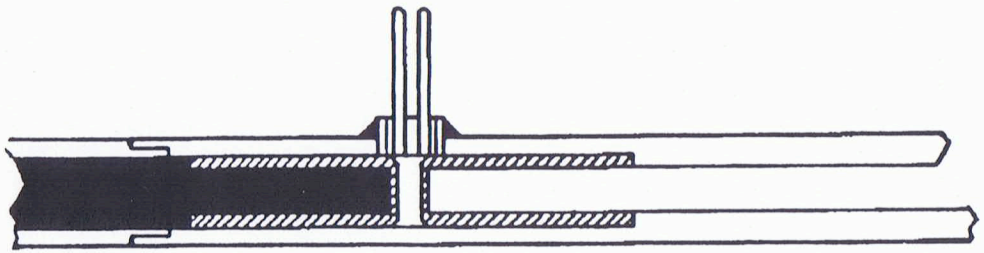
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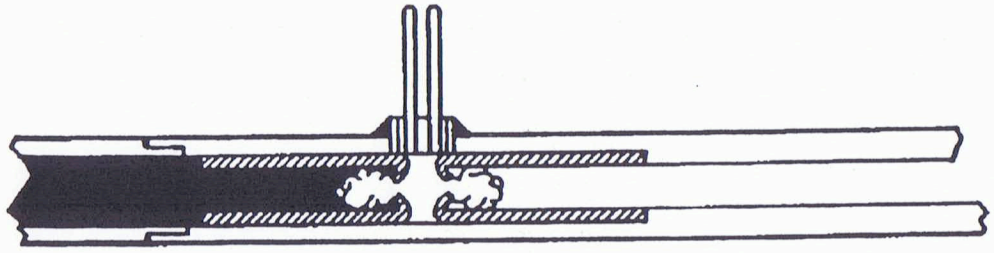
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EXPLODING DISK VALVE OPERATIONAL SEQUENCE

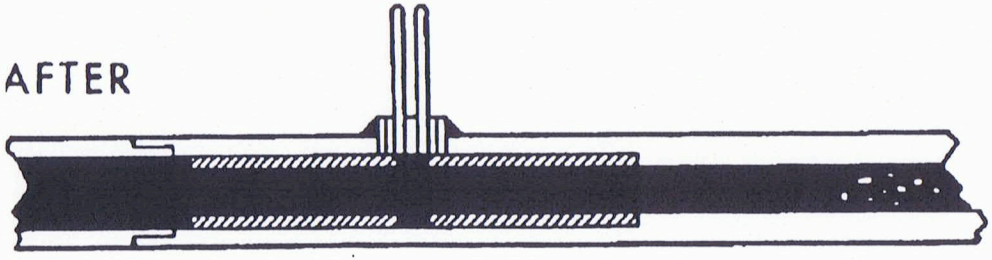


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DURING



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UNIQUE DESIGN PROBLEMS IN TRITIUM RESERVOIRS (U)

- *System*
  - Must Deliver In Specified Time
  - Must Be Consistent
  - Satisfy Weight And Space Requirements
  - Fire And Accident Considerations

- *Long Term Degradation*
  - Subject To Hydrogen Embrittlement
  - Subject To Helium Embrittlement
  - Withstand Pressure Increase With Time
  - Subject to Radiation Induced Effects (Loss of Permeability, Stoichiometry)

- *Safety*
  - Must Be Super Safe Against
    - Burst
    - Permeation (Walls, Welds, Stringers)

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Consequences of a stockpile tritium release:

a. Weapon reliability

b. Personnel safety

c. Political/environmental ramifications

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Helium from tritium decay produces cumulative, irreversible damage in stockpile materials

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Specifications

- •Narrow chemistry——promotes weldability
- •Grain size——less than ASTM 5
- •Vacuum—arc—remelt (VAR) material
  - Inclusions——ultraclean
  - Ferrete distribution—— < 3% minimize stringers

Acceptance

- •Chemistry
- •Metallography
  - Grain size
  - Ferrite distribution
  - Inclusion
- •Ultrasonics——porosity

For tritium reservoirs, it is necessary to improve the material properties

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It is most important to clean all surfaces of undesirables

CLEANING

Why

- To remove residues and oxides which could interface with welding, plating, or heat treating processes
- To remove any metallic materials imbedded into the surfaces permitting the formation of a continuous protective oxide film
- To prevent sources of rusting and corrosion on the surfaces
- To remove contaminants which could react with tritium

How

- Detergent solutions agitated ultrasonically
- Nitric acid solutions for dissolving imbedded copper and iron particles
- Nitric—hydrofluoric acid solutions for dissolving oxide films and imbedded particulate matter, and to etch certain stainless steel alloys
- Freon and alcohol rinsing for removing organic contaminants
- High purity water for rinsing
- High temperature vacuum bake

We take extreme care to verify cleanliness

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CLEANLINESS VERIFICATION

- Monitor the resistivity of the rinse water to verify the absence of ionizable material
- Use analytical rinses to check for organic and inorganic contaminants with infrared spectrophotometer and ion chromotagraphy
- Perform particulate analysis on each reservoir
- Check for imbedded iron particles with a copper sulfate test
- Borescopic examination where applicable
- Visual examination for discoloration, staining, or superficial corrosive attack

Both piece parts and assemblies are cleaned prior to inspection

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Inspection and gaging costs approximate one-third of the piece part costs

INSPECTION AND GAGING

To assure:

- Interchangeability of piece parts
- Fit with next assembly
- Conformation with engineering drawings

We inspect and gage using:

- In process monitoring—feedback
- Open——set up inspection
- Dedicated gages
- Contour gages
- Air gages——non-contact
- Statistical sampling
- Control of numerical machine tapes
- Coordinate measuring machines

To minimize scrap and rework costs, we inspect early in the process

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Mechanical joints are not used for storage of tritium

ASSEMBLY AND JOINING

Joining:

- Weldments
  - Gas-tungsten are——autogenous and wire feed
  - Electron beam——autogenous and wire feed
  - Laser
  - Friction
  - Inertia
  - Resistance forge weld
- Brazes
  - Copper
  - Copper-silver-tin

Inspection and Control:

- Process monitor
- Radiographic
- Ultrasonic
- Dye Penetrant

All pressure rated components are pressure tested

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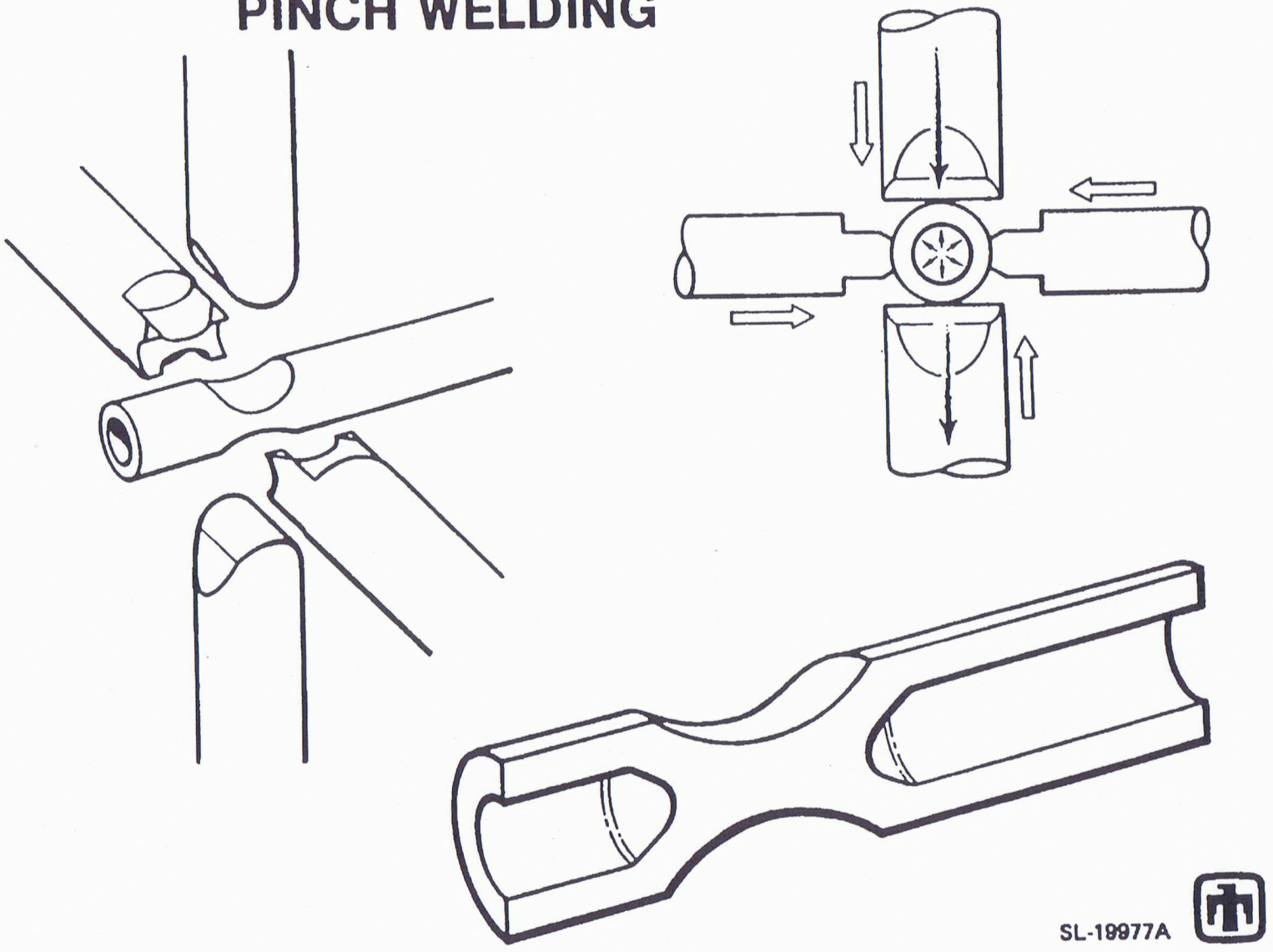
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PINCH WELDING



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Crack growth experiments show tritium (and helium) to be much more deleterious than hydrogen or deuterium.

No crack growth is seen in HYDROGEN

Crack growth is seen in TRITIUM

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PRODUCT DEVELOPMENT (U)

AT SANDIA - R&D

- MATERIALS SELECTION AND TESTING
  SPECIMEN AND STRUCTURAL ANALYSIS
- COMPONENT DESIGN
  DRAWING AND SPECIFICATIONS
- PROTOTYPE DEVELOPMENT
  FABRICATION AND JOINING
- COMPONENT EVALUATION
  STORAGE AND STRUCTURAL TESTING
- SYSTEMS TESTING
  LABORATORY AND FLIGHT TESTS
- PRODUCT DEFINITION

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PRODUCT DEVELOPMENT (U)

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WE HAVE NO REASON TO ASSUME WE FOUND ALL THE TRITIUM SURPRISES

It is not possible to extrapolate with

adequate confidence, tritium effects on components

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION XIV

- RADAR FUZING TECHNOLOGY
- OTHER FUZING MODES
- ADVANCED FUZING CONCEPTS

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Nuclear Weapon Fuzing Technology

- Introduction to Fuzing Components & Systems
- Radar Fuzing
- Contact Fuzing
- Inertial, Barometric, and Timer Fuzes
- Fuzing Systems
- ***Future*** Fuzing Systems
  - SLBM Warhead Protection Program

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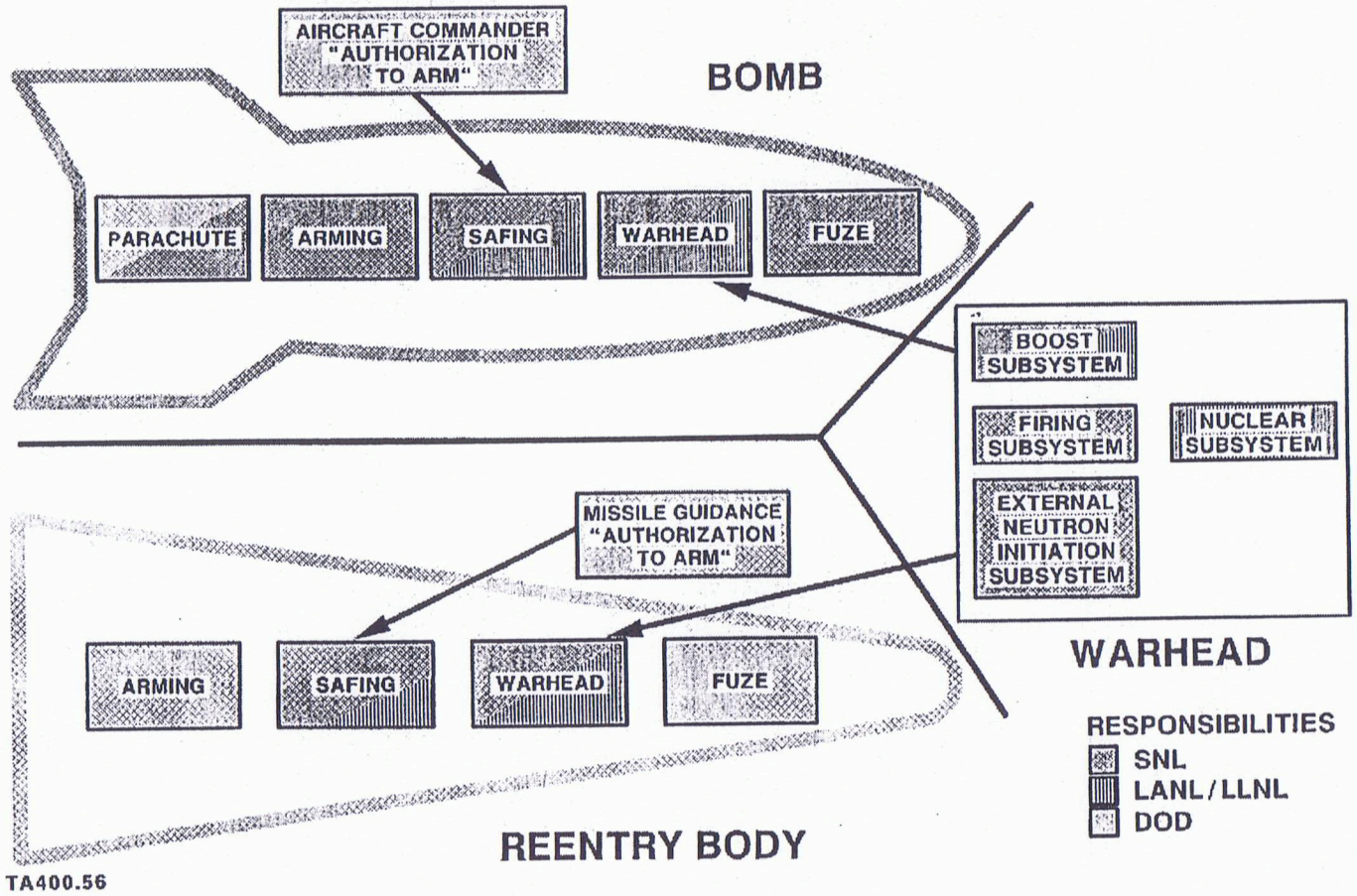
What is a Fuze ?

- Mechanism(s) within a weapon responsible for optimizing the location of weapon detonation
- Initiates the final, irreversible phase of weapon detonation
  - Follows "arming" functions, which are
    - reversible
    - time-uncritical
  - Precedes "firing"

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Fuzing System Hierarchy

Components:

Radars
(Antennas)

Clocks

G-switches

Pressure sensors
(Baro/hydro)

Accelerometers

Programmers

Crush sensors

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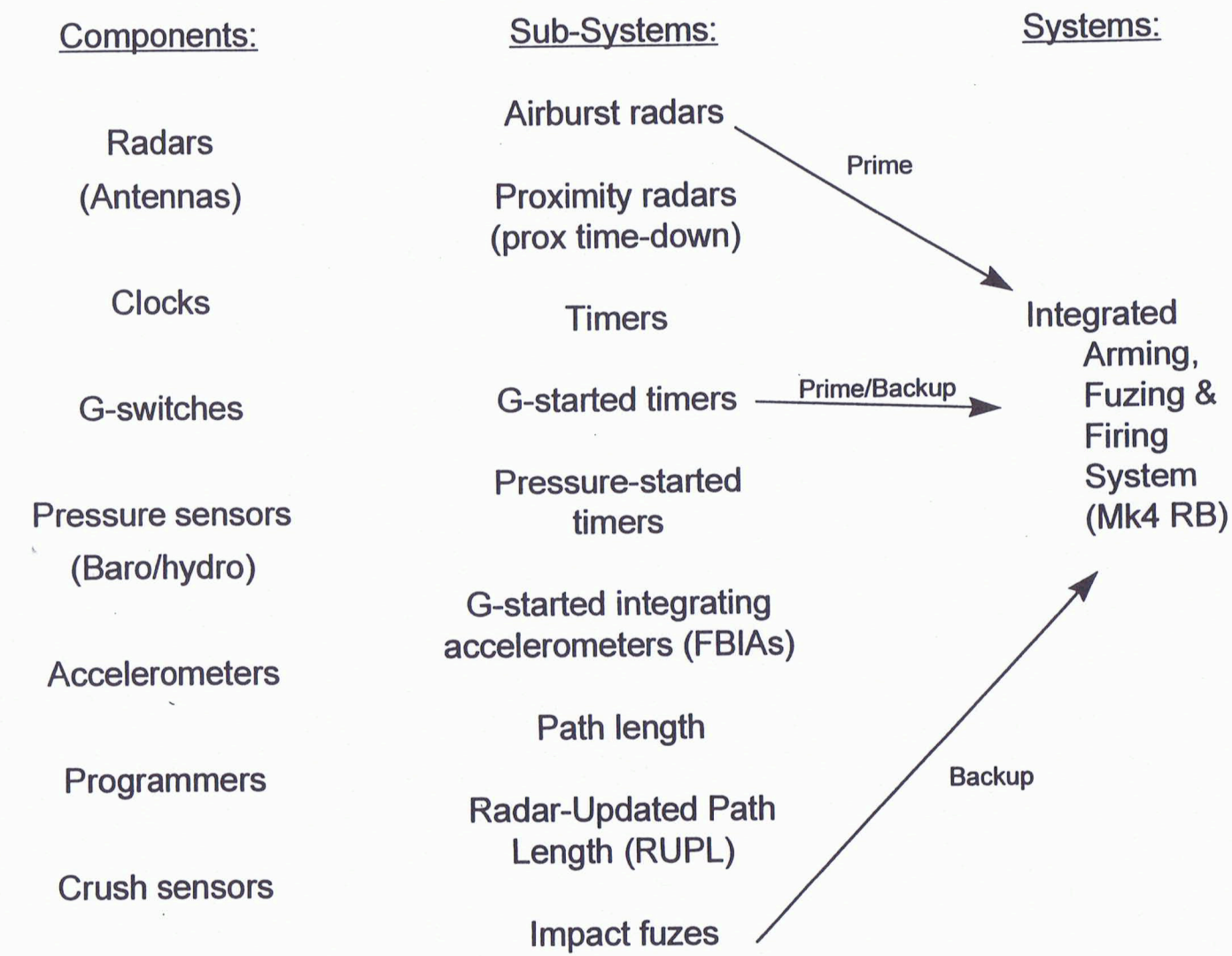
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Fuzing System Hierarchy

Components:	Sub-Systems:
Radars (Antennas)	Airburst radars
	Proximity radars (prox time-down)
Clocks	Timers
G-switches	G-started timers
Pressure sensors (Baro/hydro)	Pressure-started timers
Accelerometers	G-started integrating accelerometers (FBIAs)
Programmers	Path length
Crush sensors	Radar-Updated Path Length (RUPL)
	Impact fuzes

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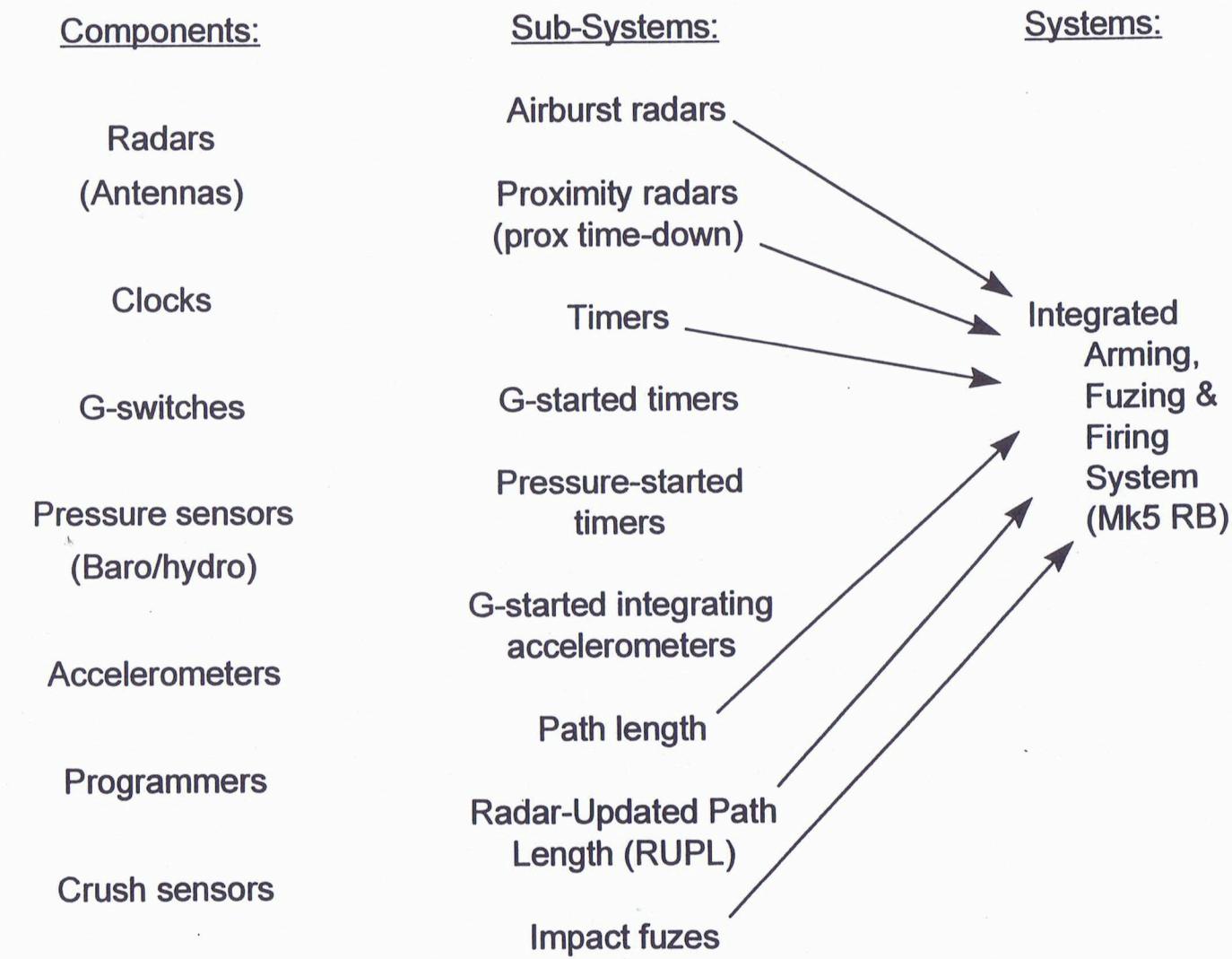
Fuzing System Hierarchy



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Fuzing System Hierarchy



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How is a Fuze selected?

Traditional fuzing system priorities:

- Reliable
- Light weight (reentry body)
- Accurate
- Small (reentry body)
- Flexible
- Testable
- Producible
- Inexpensive

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How is a Fuze selected?

Future fuzing systems must be:

- Inexpensive
- Producible
- Reliable
- Accurate
- Certifiable (test & analysis)
- Flexible
- Small (reentry body)
- Light weight (reentry body)

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Radar Fuzing

- Role of radar fuzing
- Basic radar fuze operation
- Radar design issues
- Current technology

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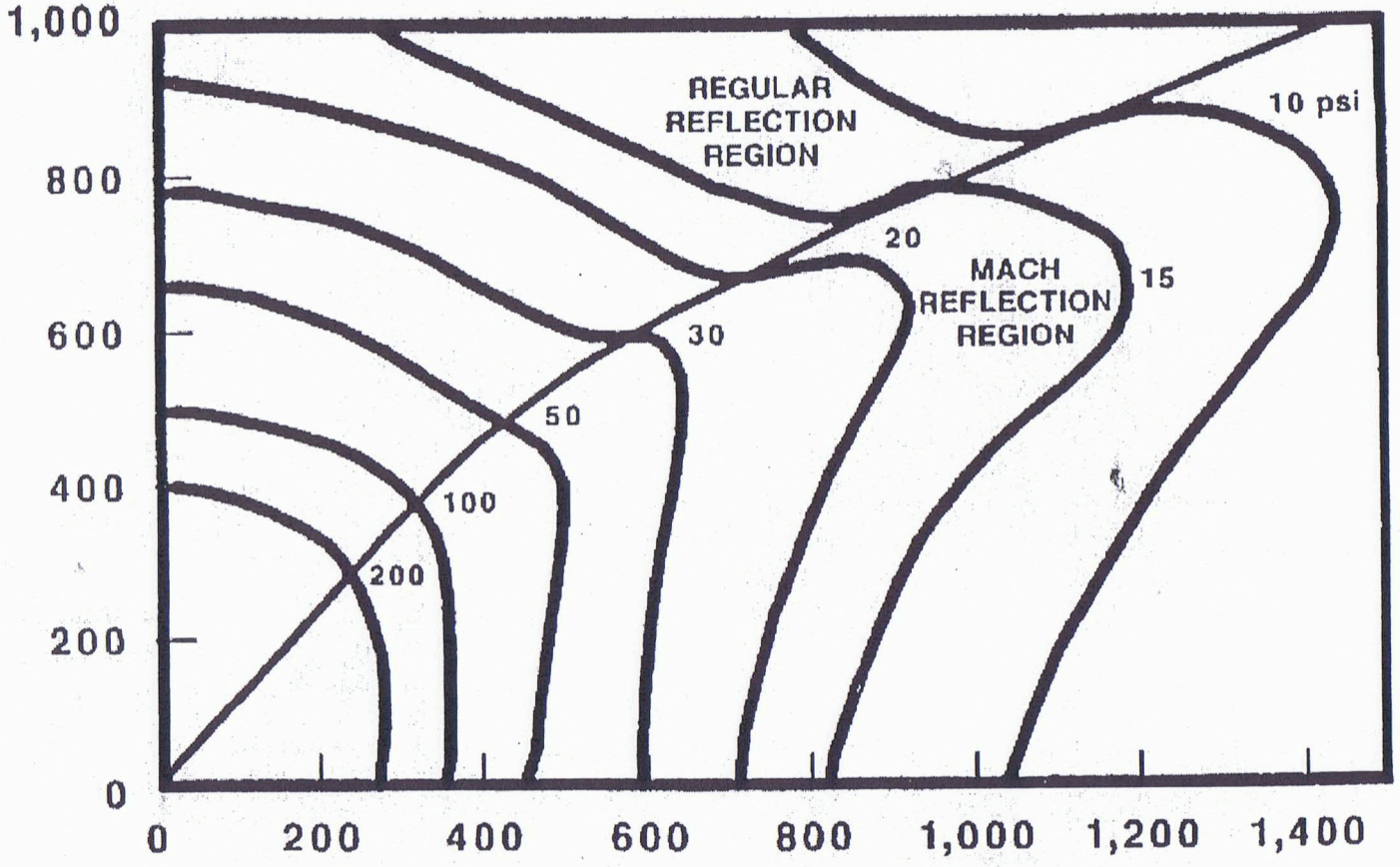
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Why use a radar ?

- Height of burst precision to maximize extent of low overpressure levels
  - setability
  - accuracy
- Height of burst control to minimize fallout
- Dependable surface fuzing
  - Ensure detonation prior to collision
- Accurate altitude reference for improving inertial fuze accuracy (radar-updated path length fuze)

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PEAK OVERPRESSURES ON THE GROUND FOR A 1-KILOTON BURST

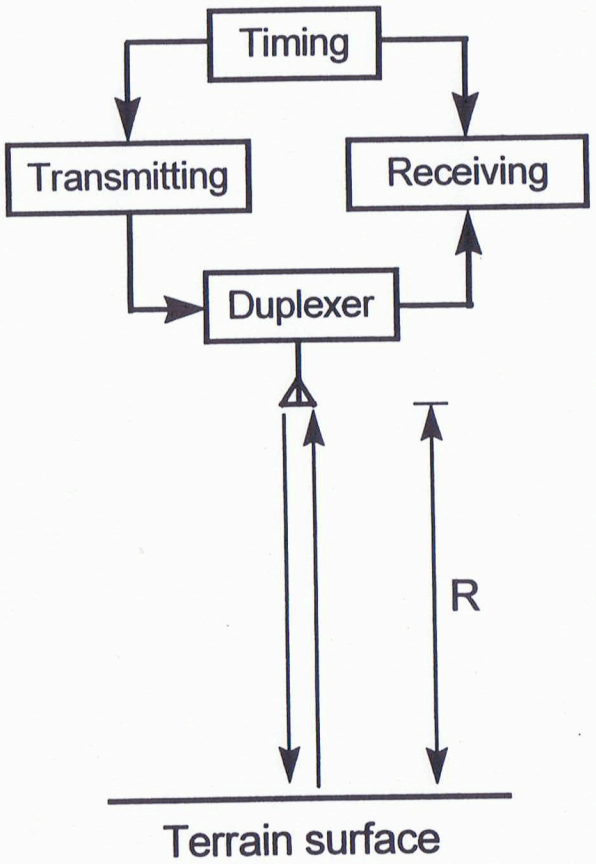


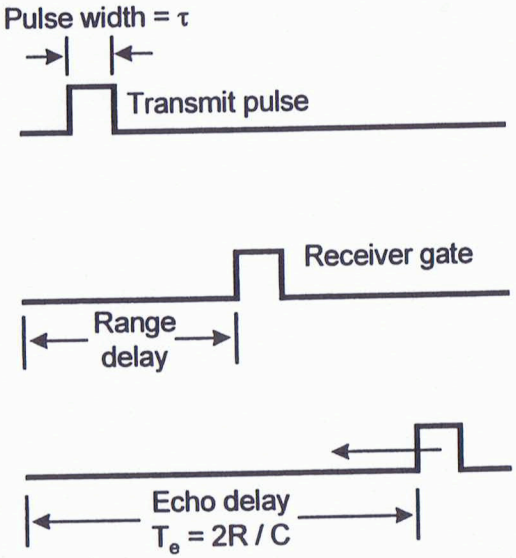
REFERENCE: GLASSTONE AND DOLAN, THE EFFECTS OF NUCLEAR WEAPONS, 3RD EDITION US DOD AND DOE, 1977

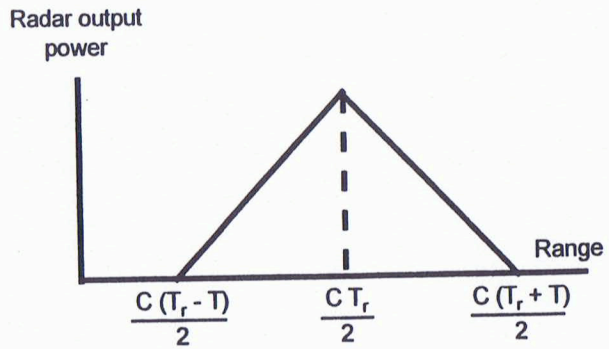
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Basic Radar Operation







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Radar design considerations

- Immunity to electronic countermeasures
  - prevent premature detection of "radar-like" signals ("spoofing")
  - ensure detection of radar return in presence of RF energy saturation ("dudding")

- Plasma loss (space shuttle "black-out")
  - affects both transmit ***and*** receive
  - varies with: velocity

    altitude

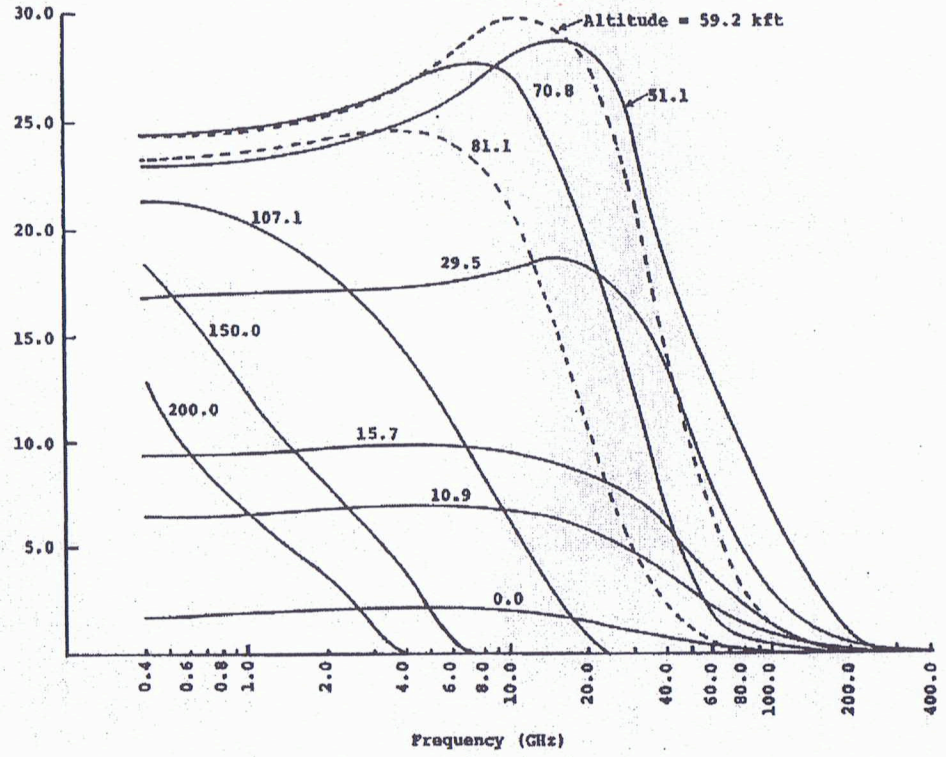
    nosetip and heat shield materials

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One-way plasma loss vs. frequency for ABRV-3 trajectory



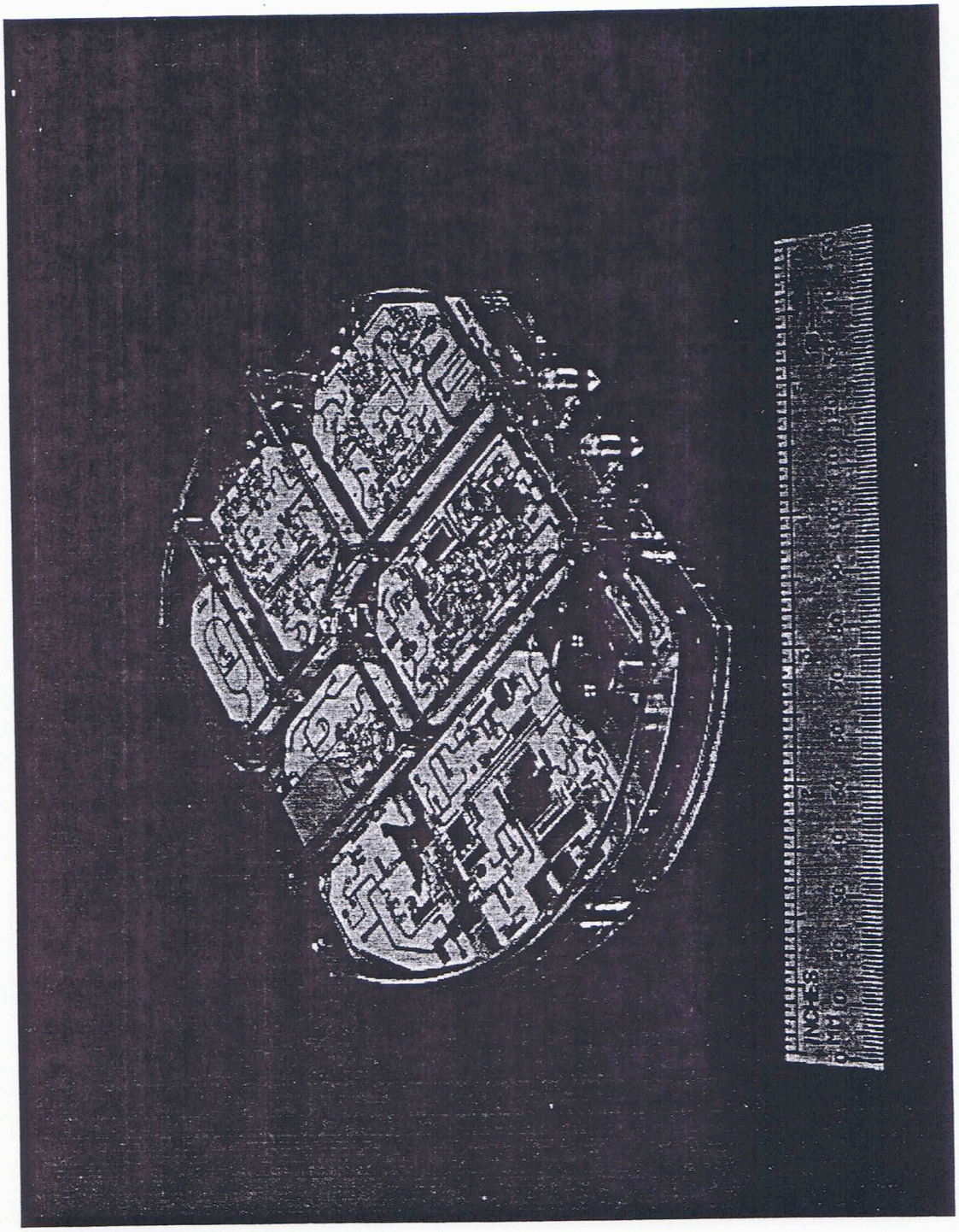
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Radar design considerations, cont'd

- Antenna gain patterns
  - affects both transmit ***and*** receive
  - must accommodate all flight path angles and roll orientations
- Target reflectivities
  - peak reflectivity & angular attenuation
- Frequency
  - Higher frequencies required for proximity fuze narrow pulse width
  - Higher frequencies require less "real estate" for antenna windows
    - Smaller antennas thought to have less impact on reentry body flight
  - Lower frequencies have lower "path loss" requiring less receiver loop sensitivity

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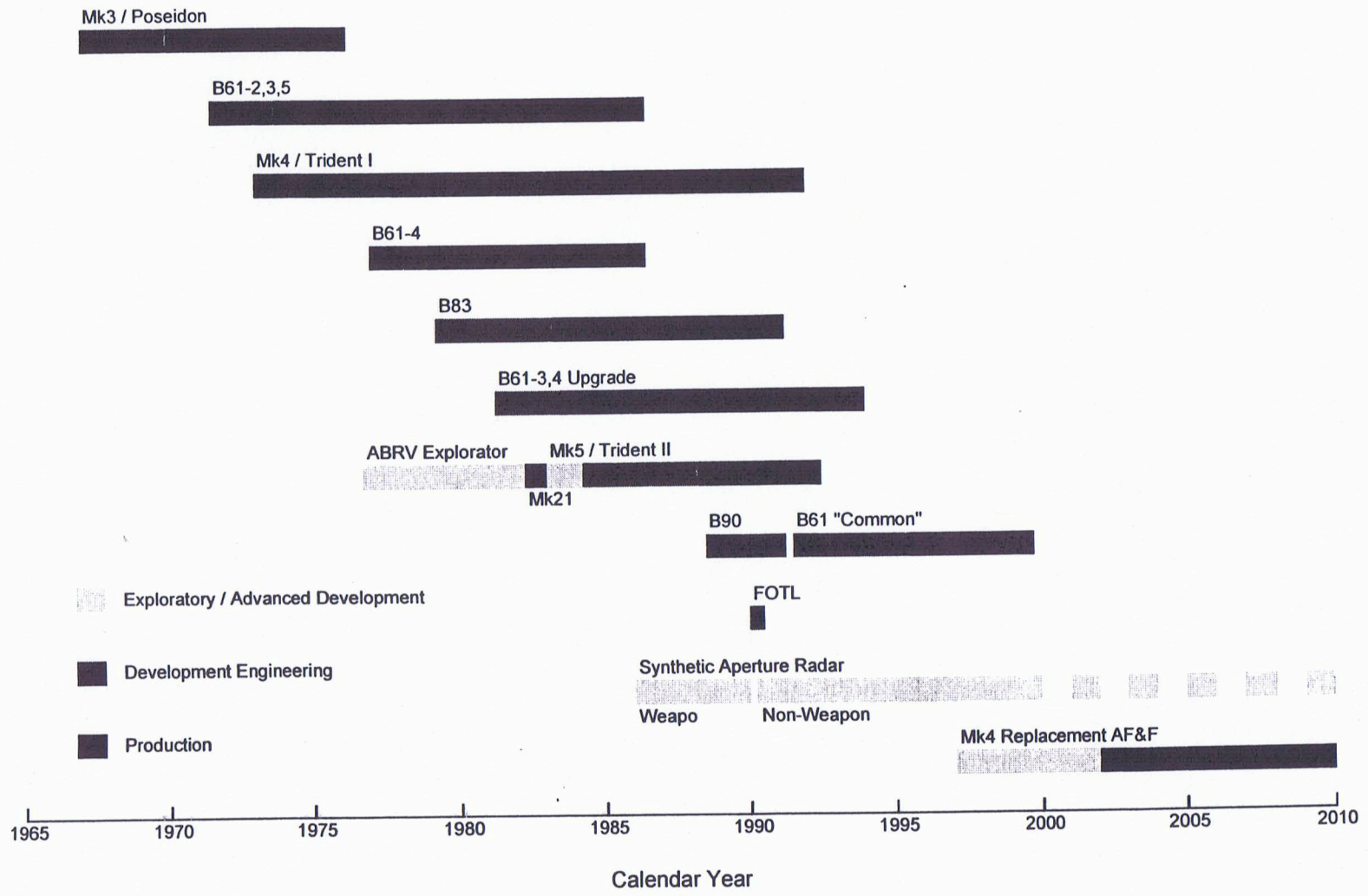
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Sandia Fuze Development & Production
(1965 - 2010)



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Contact Fuzing

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Contact fuze characteristics

- Output directly triggers firing set for fast operation

  OR

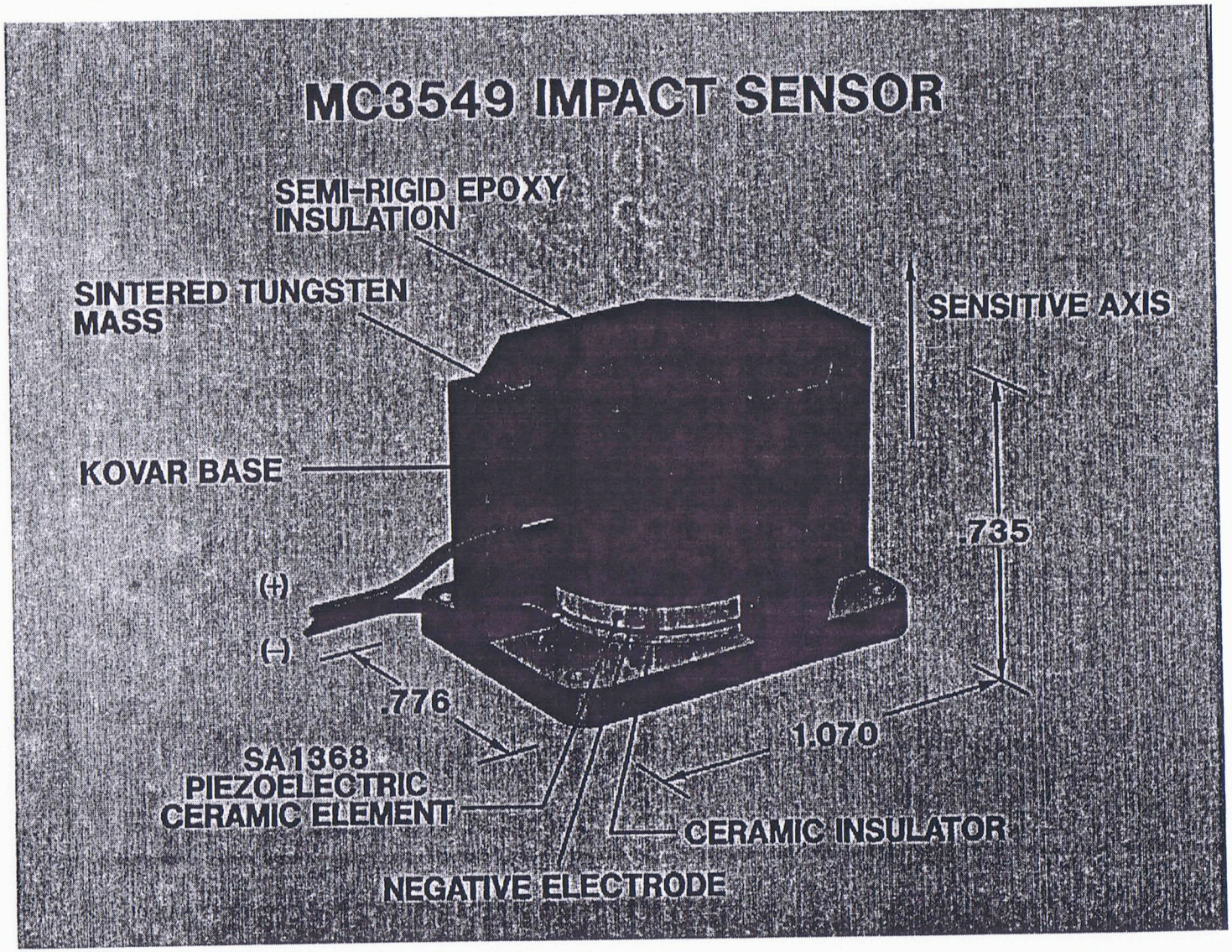
  initiates delay mechnism for weapon designed for impact survivability

- Piezoelectric materials release charge (voltage) when shocked
  - generally not requiring external "poling" or charging

- Use pervasively throughout the stockpile for both selectable and backup fuzing

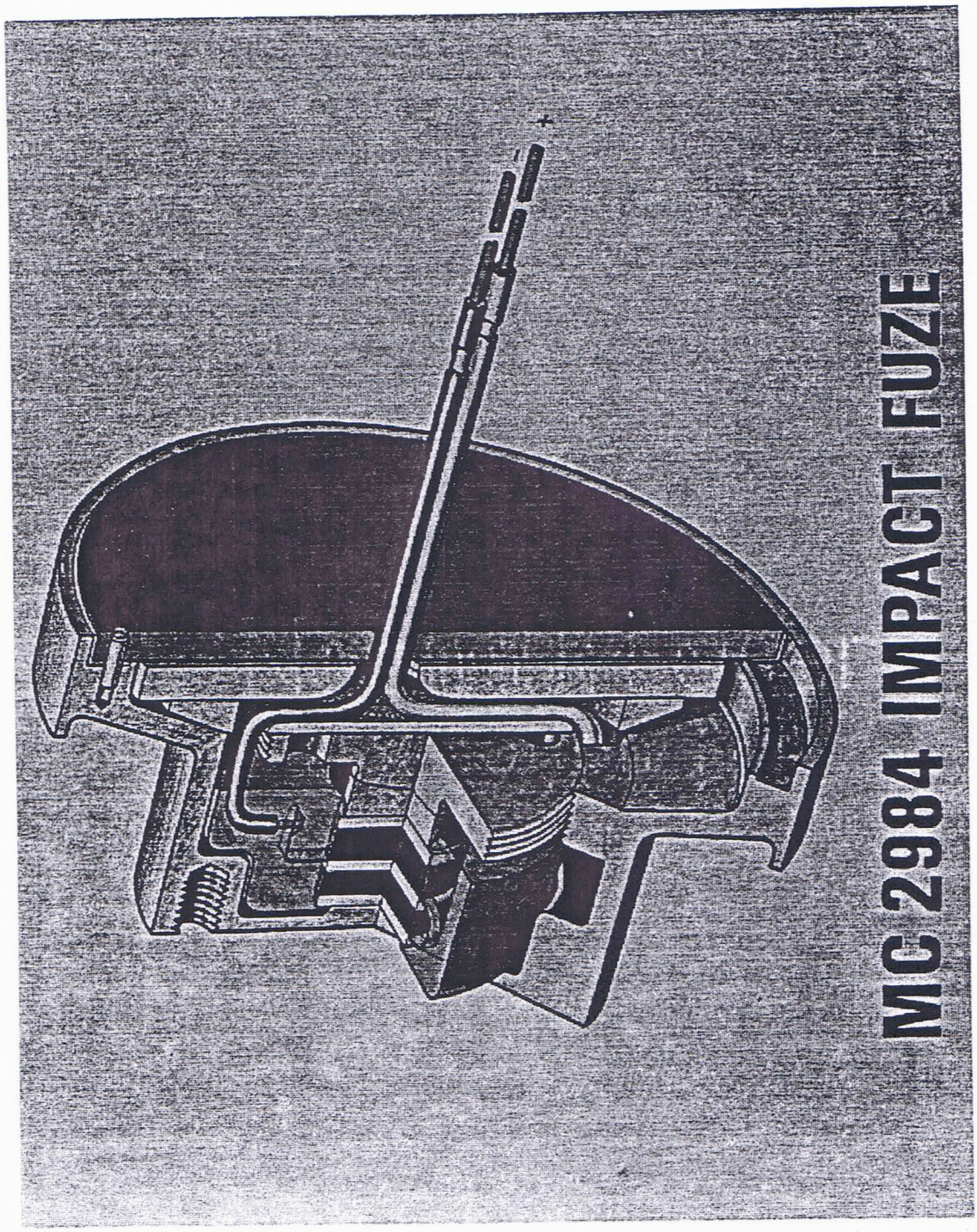
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MC 2984 IMPACT FUZE

Contact Fuze Characteristics

- Advantages
  - Very little penalty in weight, cost or volume
  - Desirable as backup to air burst fuzing
  - Radiation hardened and immune to jamming
  - Very reliable as a component
  - Maximizes crater volume and ground motion in comparison to other air burst options

- Disadvantages
  - Reduced "effects radius" for air burst targets
  - Range offset associated with backup role
  - Qualification / testing has been costly
  - Dependability concerns (system reliability)

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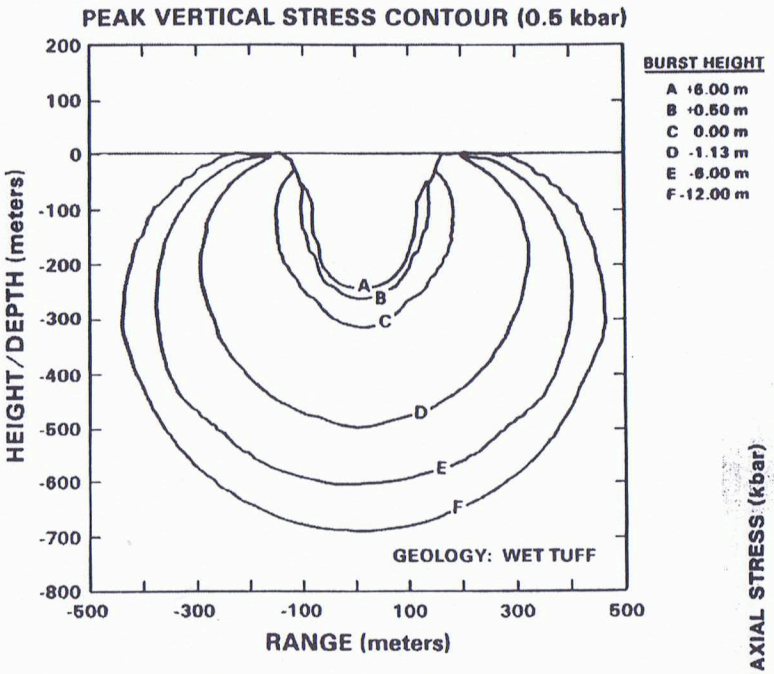
Contact fuzing degree of difficulty

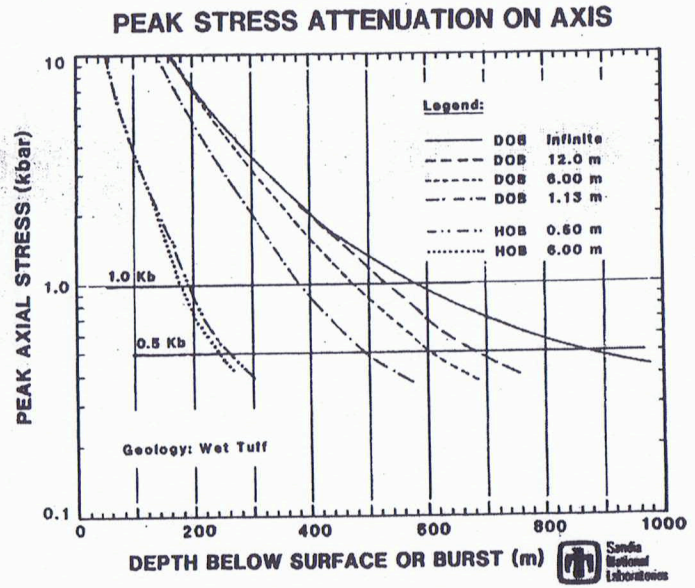
	Component	System
Design	Easy	Easy
Validate	Fairly easy	Very difficult

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Contact vs. Proximity - Ground shock environments

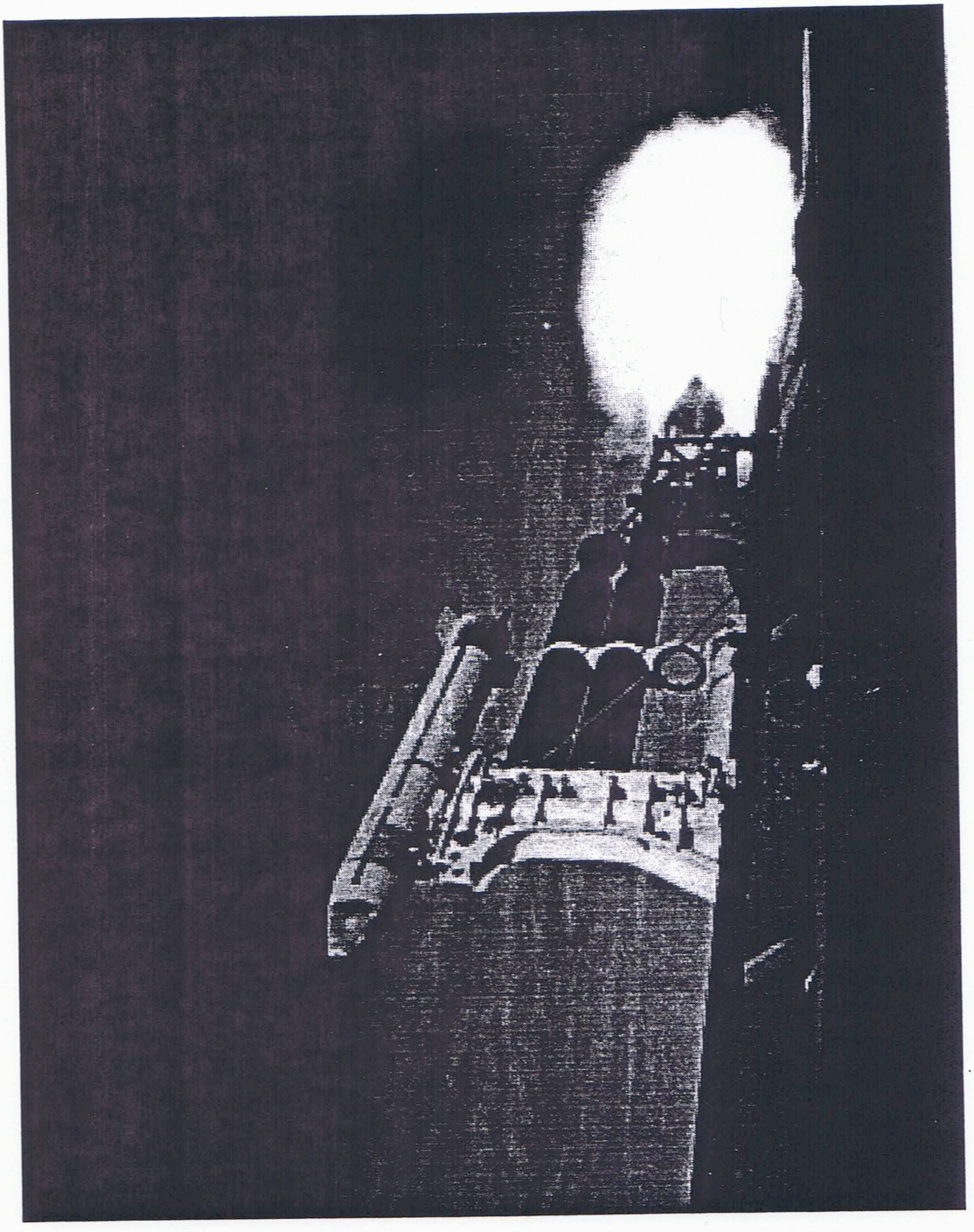




Proximity fuzing consistently results in minimal degradation in ground shock environments when compared to contact

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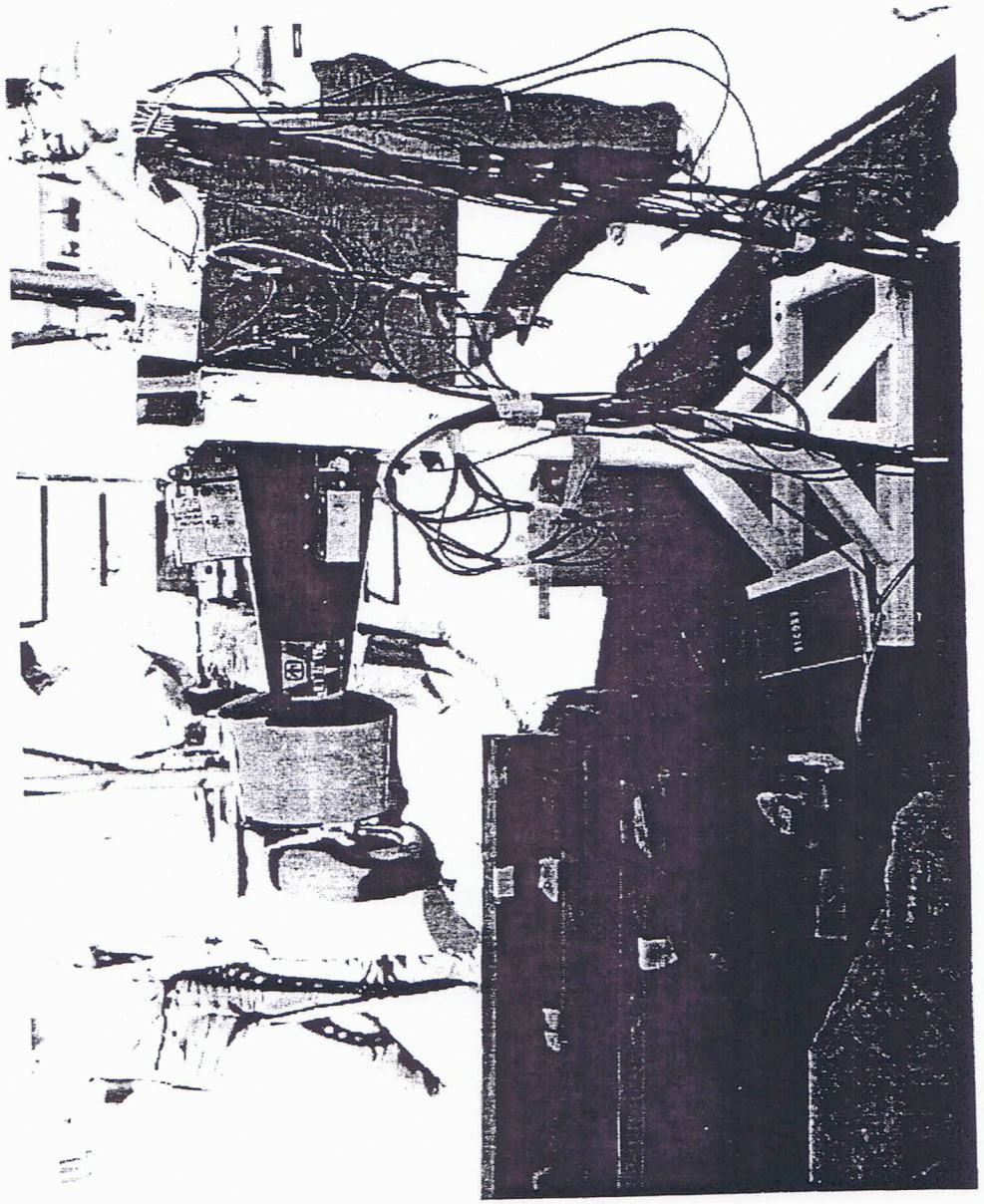
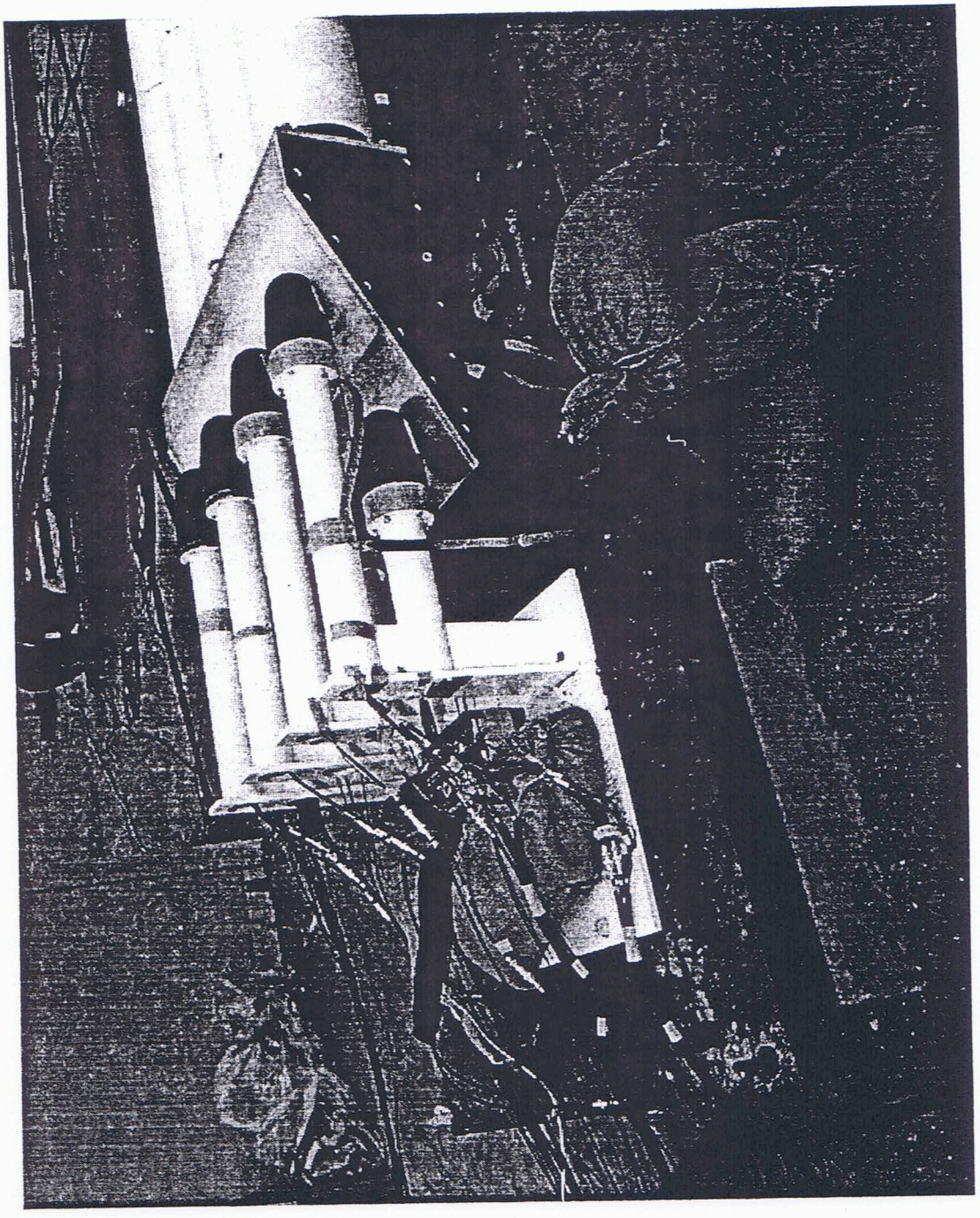
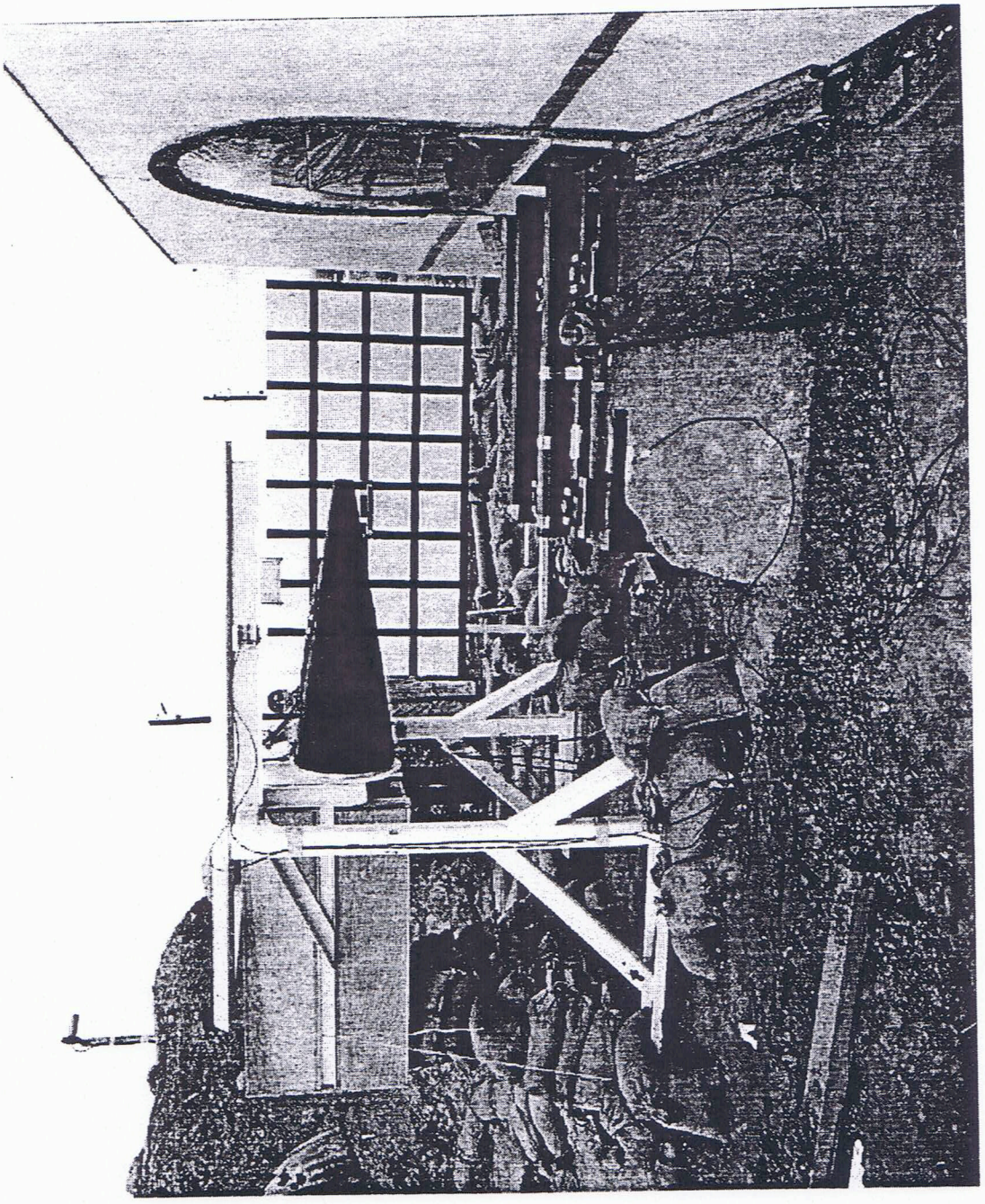
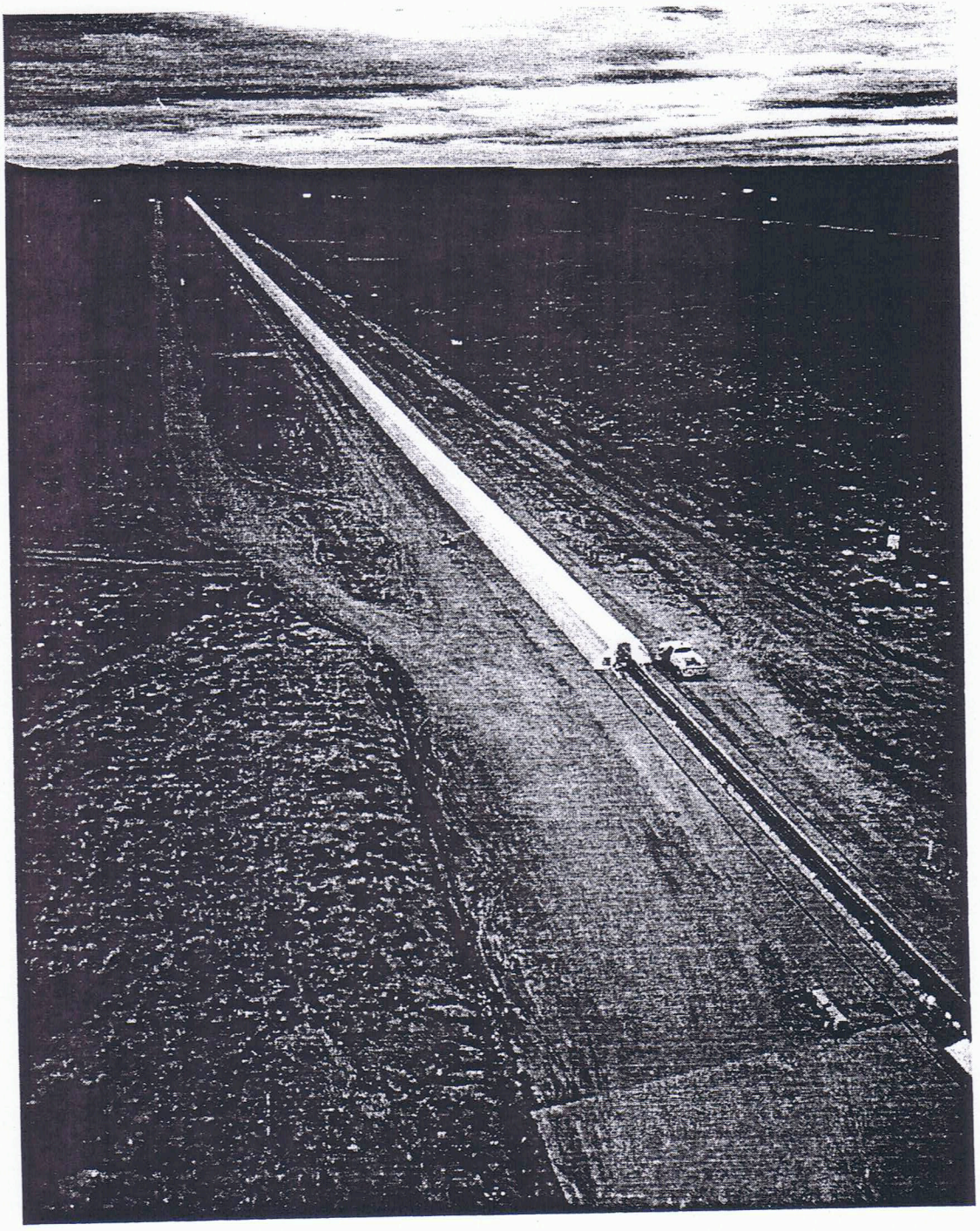


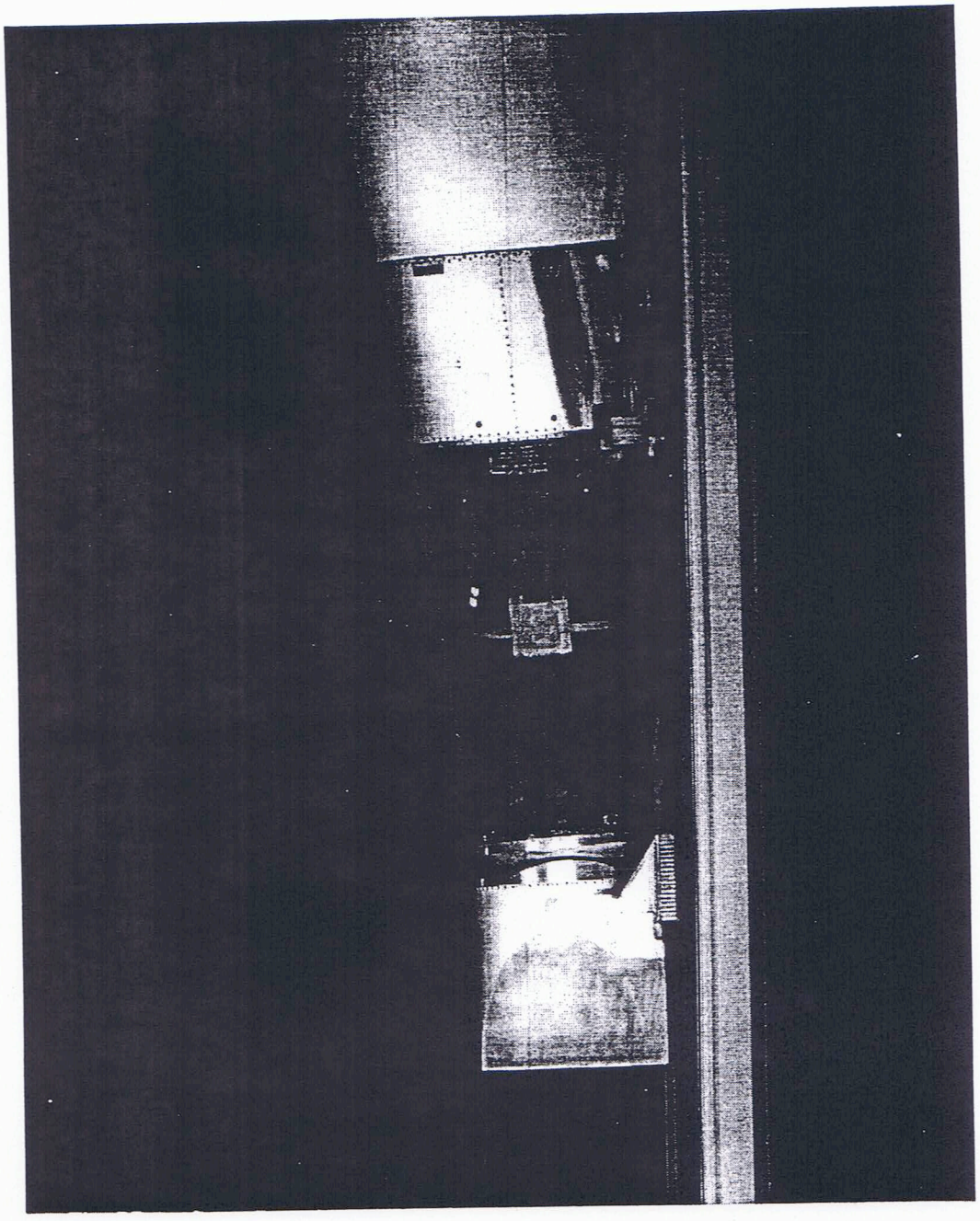
Figure 26

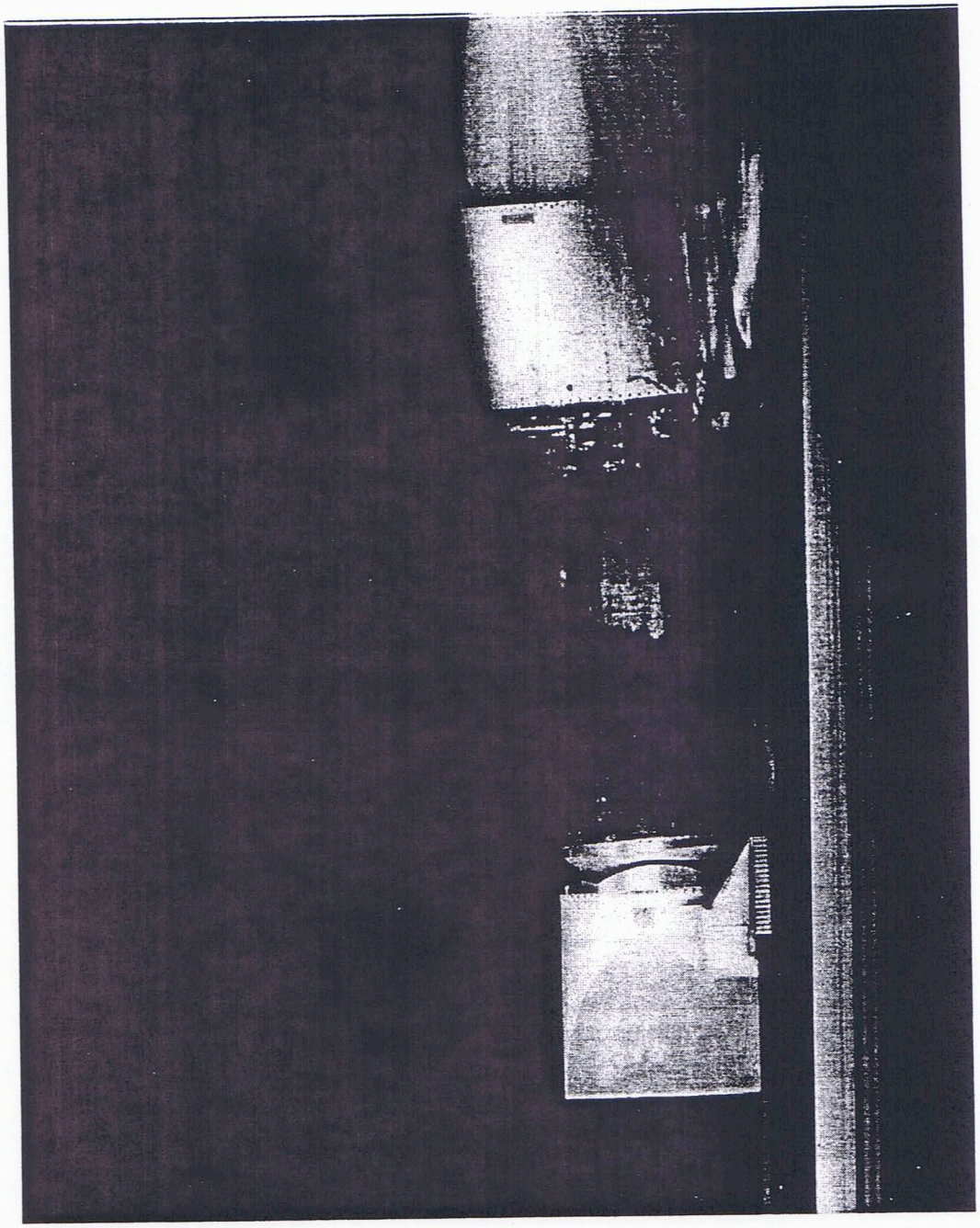
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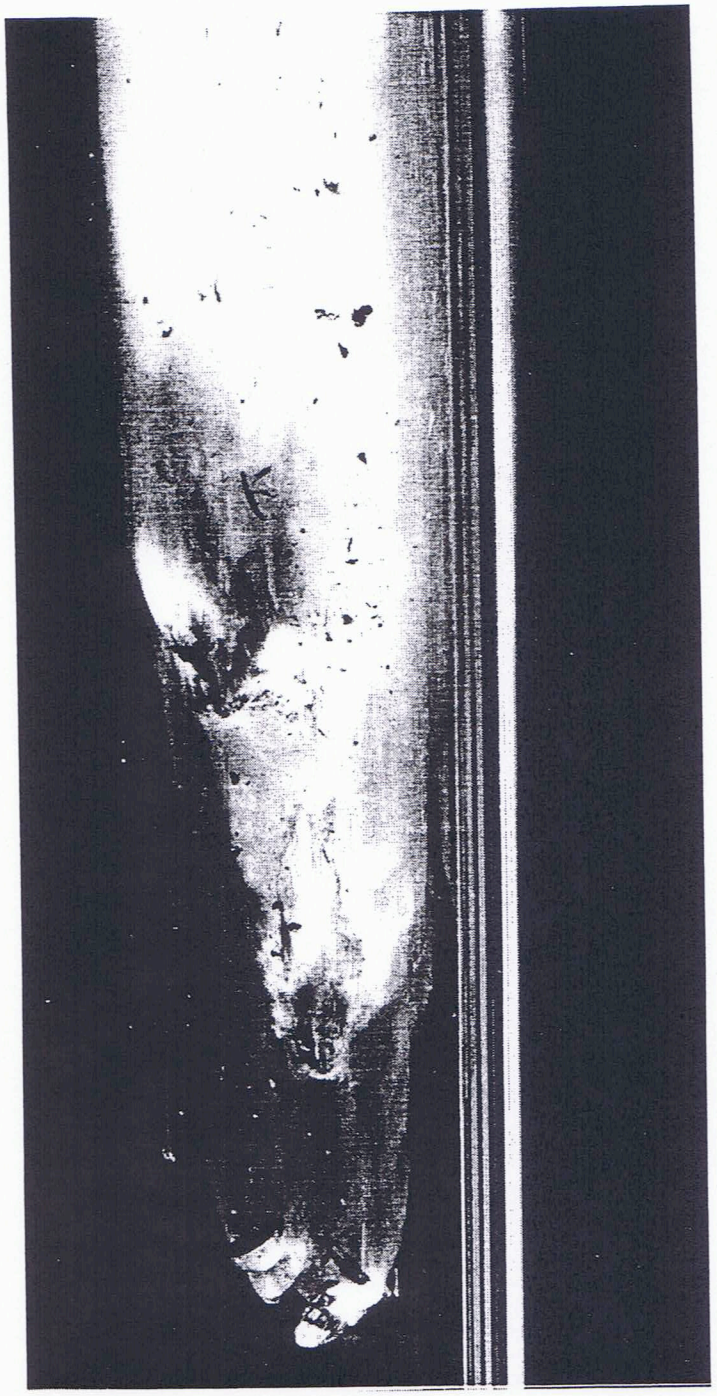




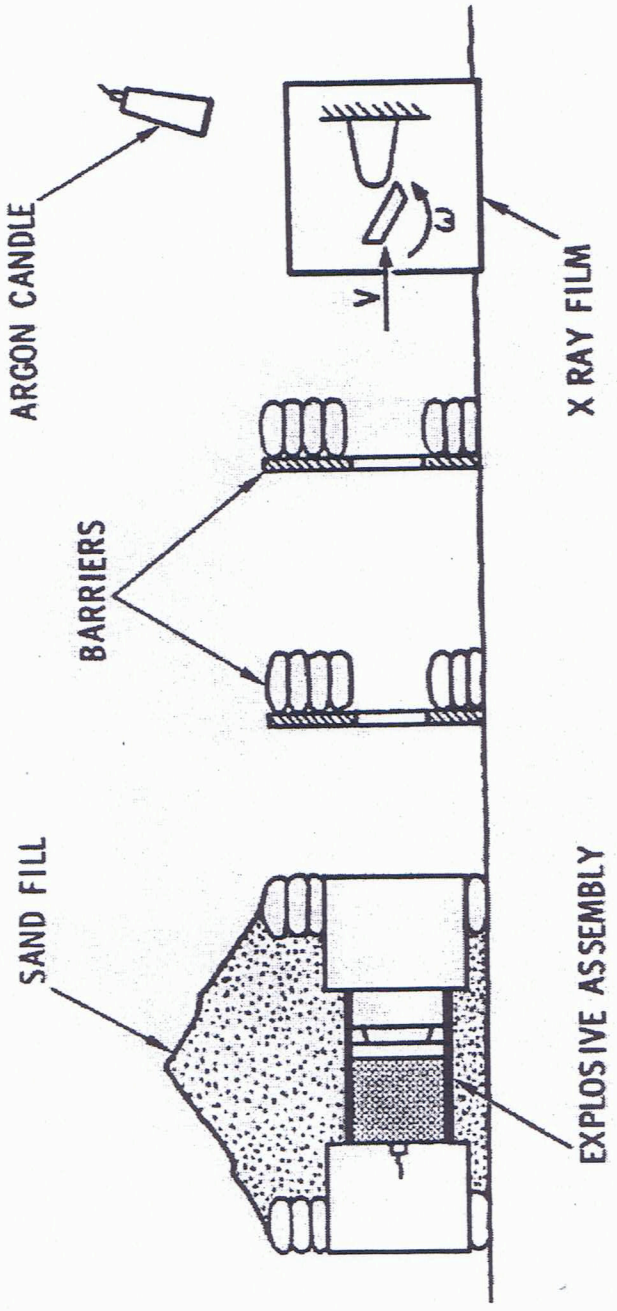


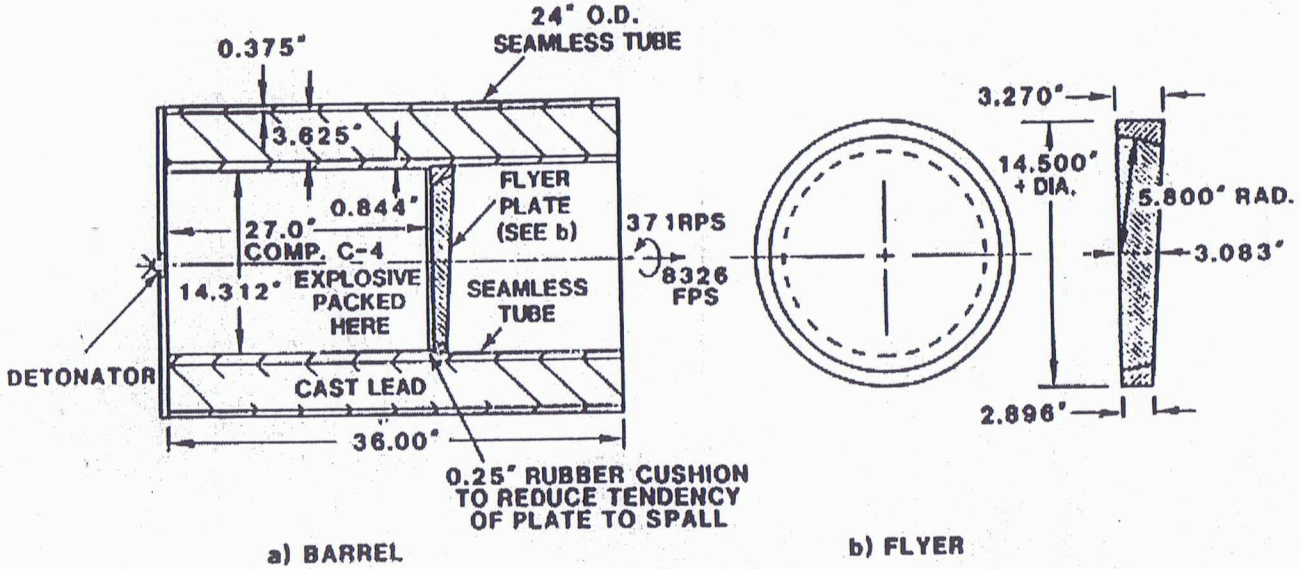









ARGON CANDLE
BARRIERS
SAND FILL
EXPLOSIVE ASSEMBLY
X RAY FILM
ω
V

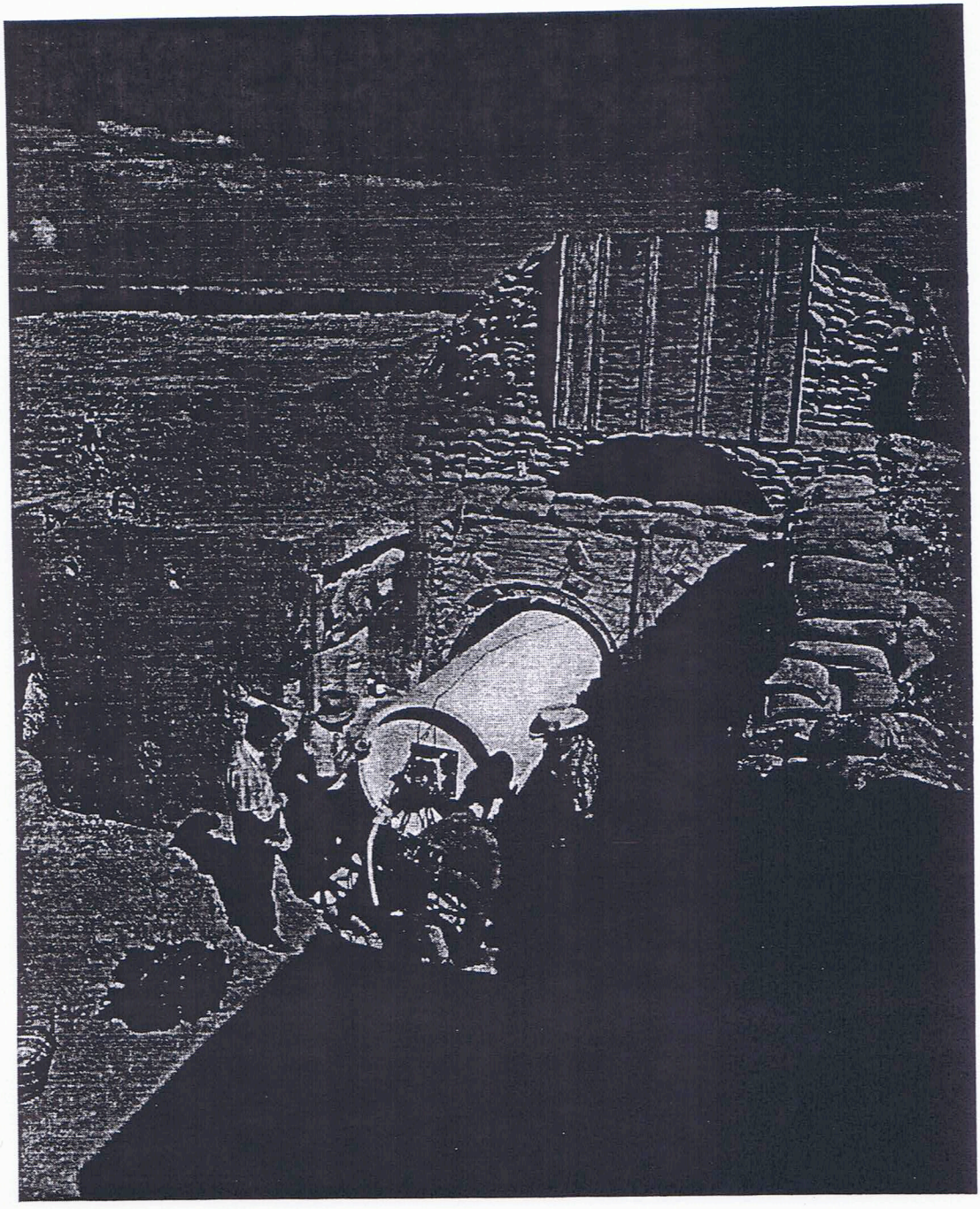


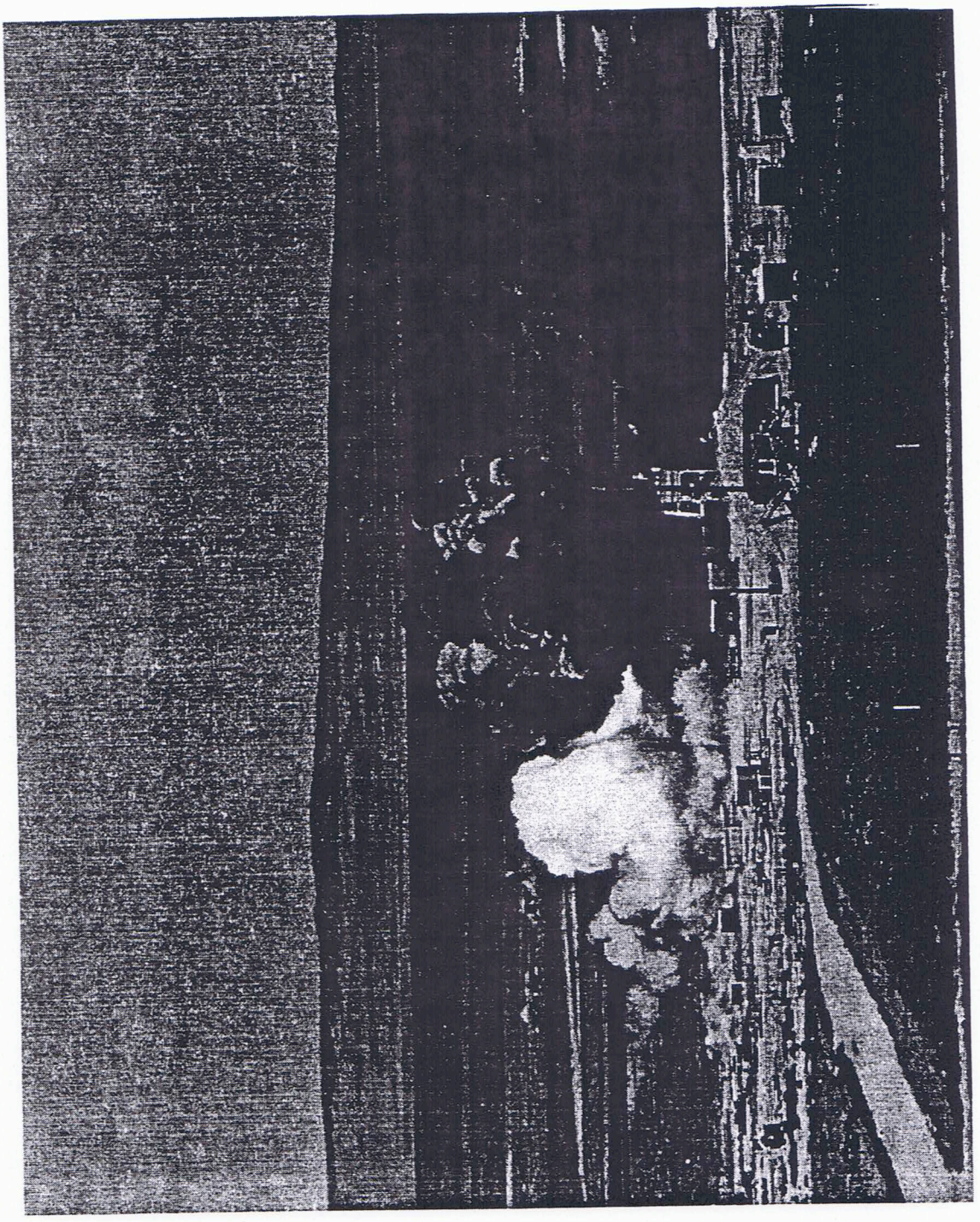
a) BARREL

b) FLYER

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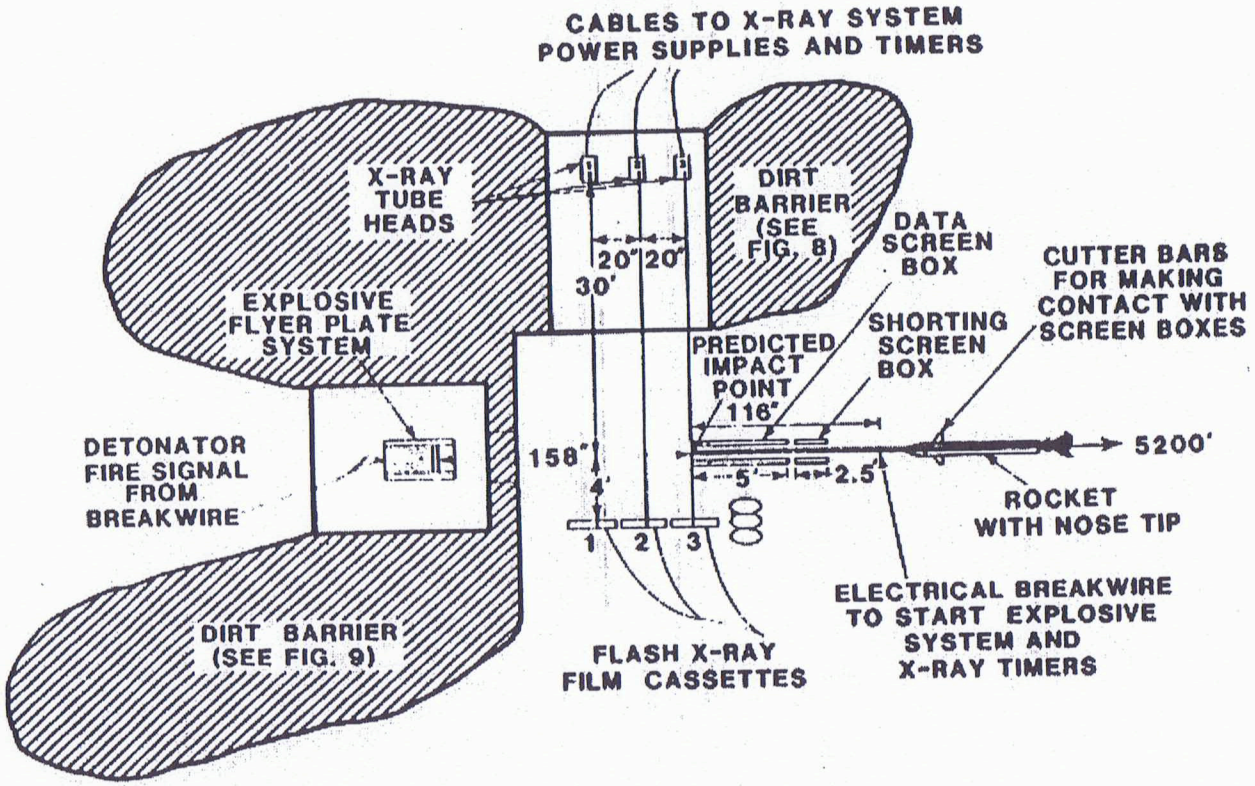
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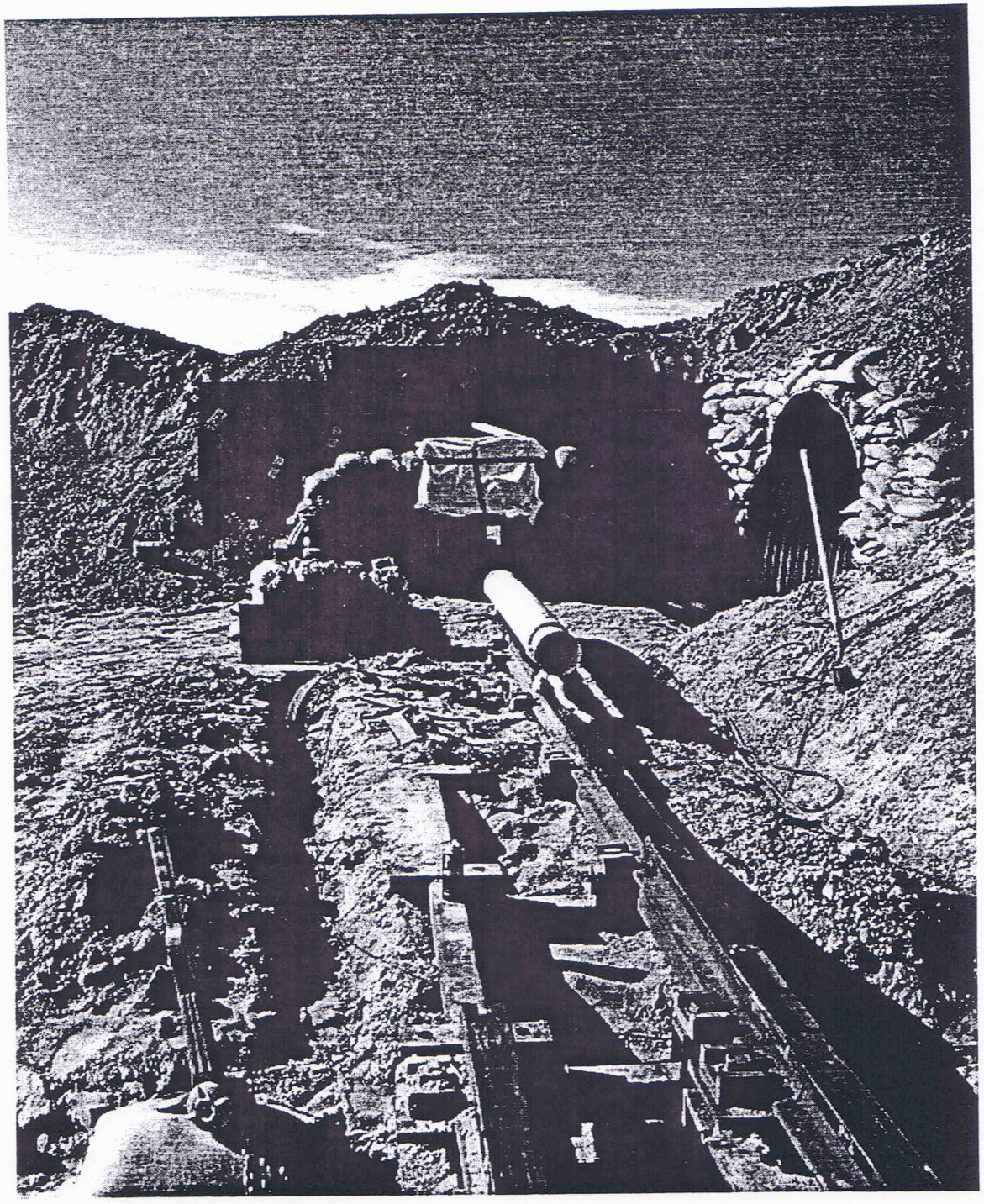
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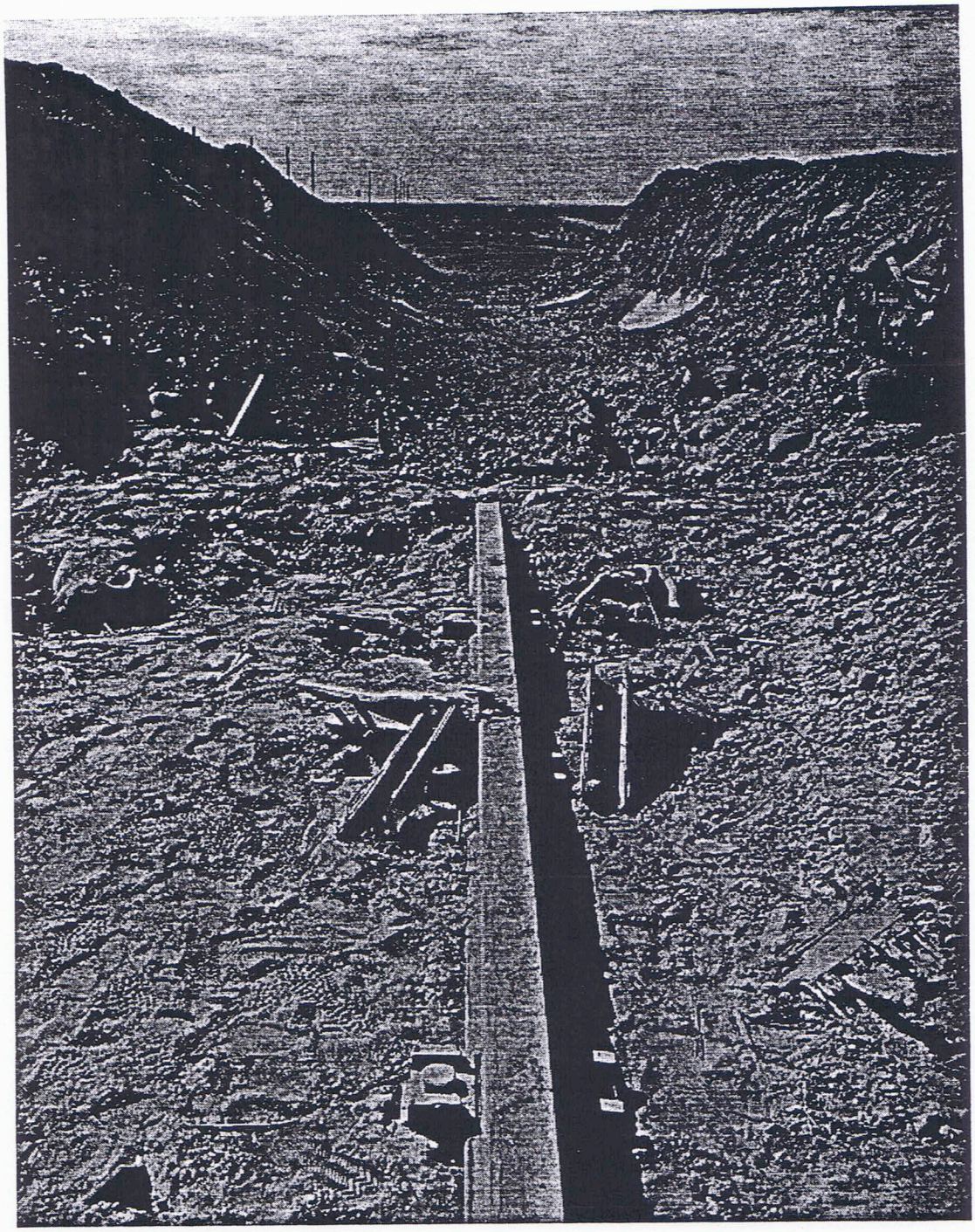
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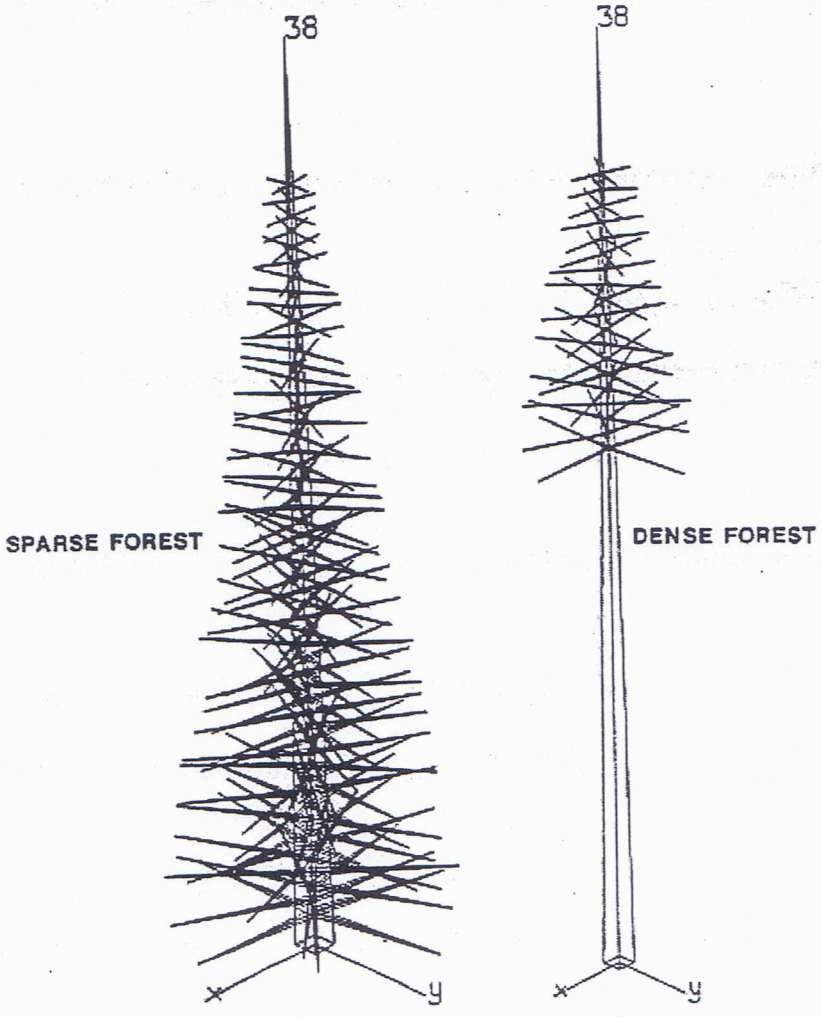


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DOE
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Pine Tree Models for Sparse and Dense Forests

View for a 100 year old pine forest, P=0.80

View for a 7 year old pine forest, P=0.13

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View for a 20° impact angle, P=0.80

View for a 40° impact angle, P=0.54

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Conditional Probabilities of Tree Impacts on the Reentry Vehicle Surface

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Improved surface fuzing concepts have been explored for every new reentry system

- Faster-responding impact sensors
  - concepts include:
    - faster-sensing mechanisms
    - forward deployment of traditional sensors
  - little, if any, additional protection against impact irregularities

- Radar proximity fuzing
  - adequate survivability for all impact scenarios
  - little, if any, degradation in burst height effectiveness

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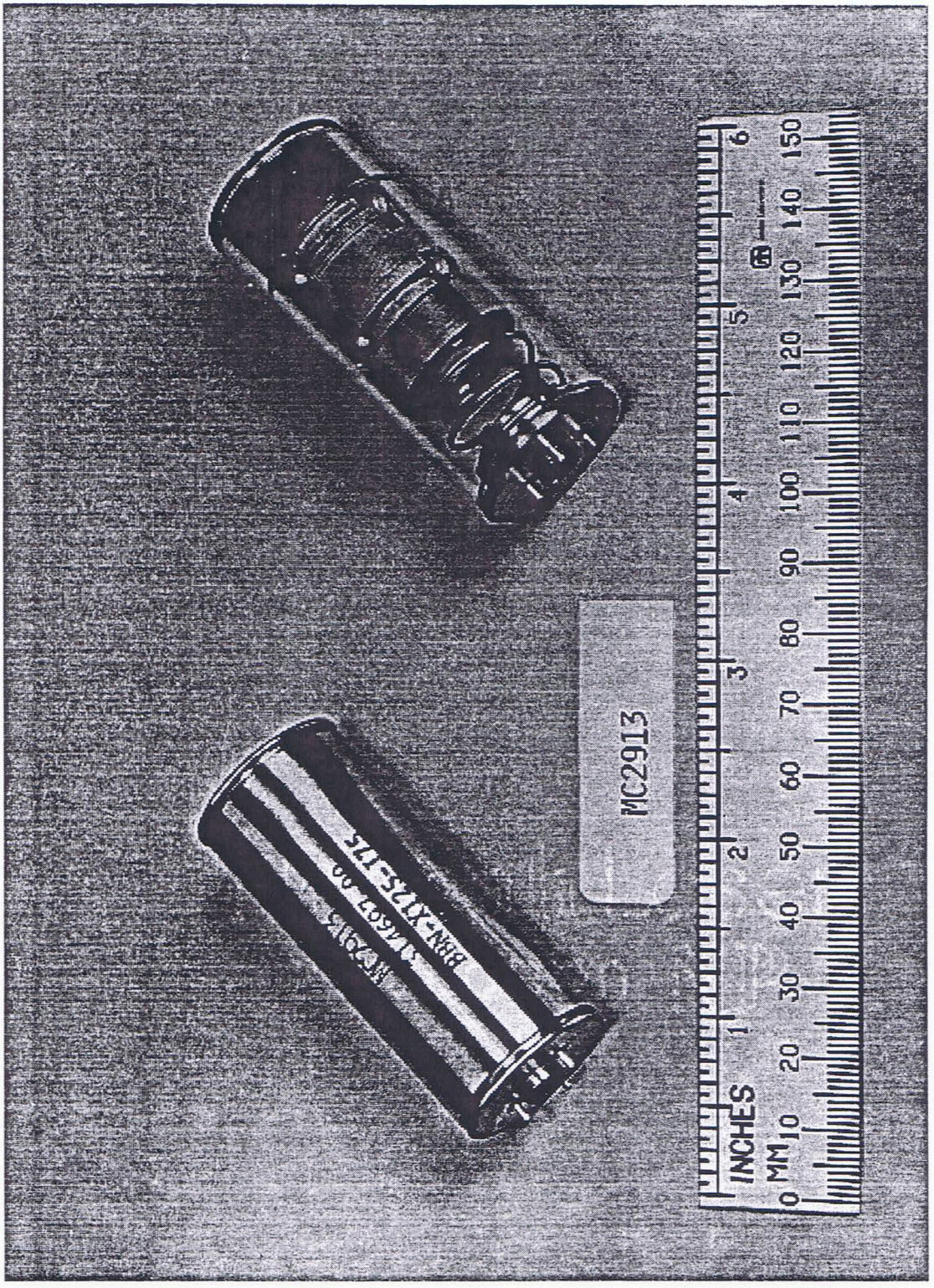
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Inertial Devices

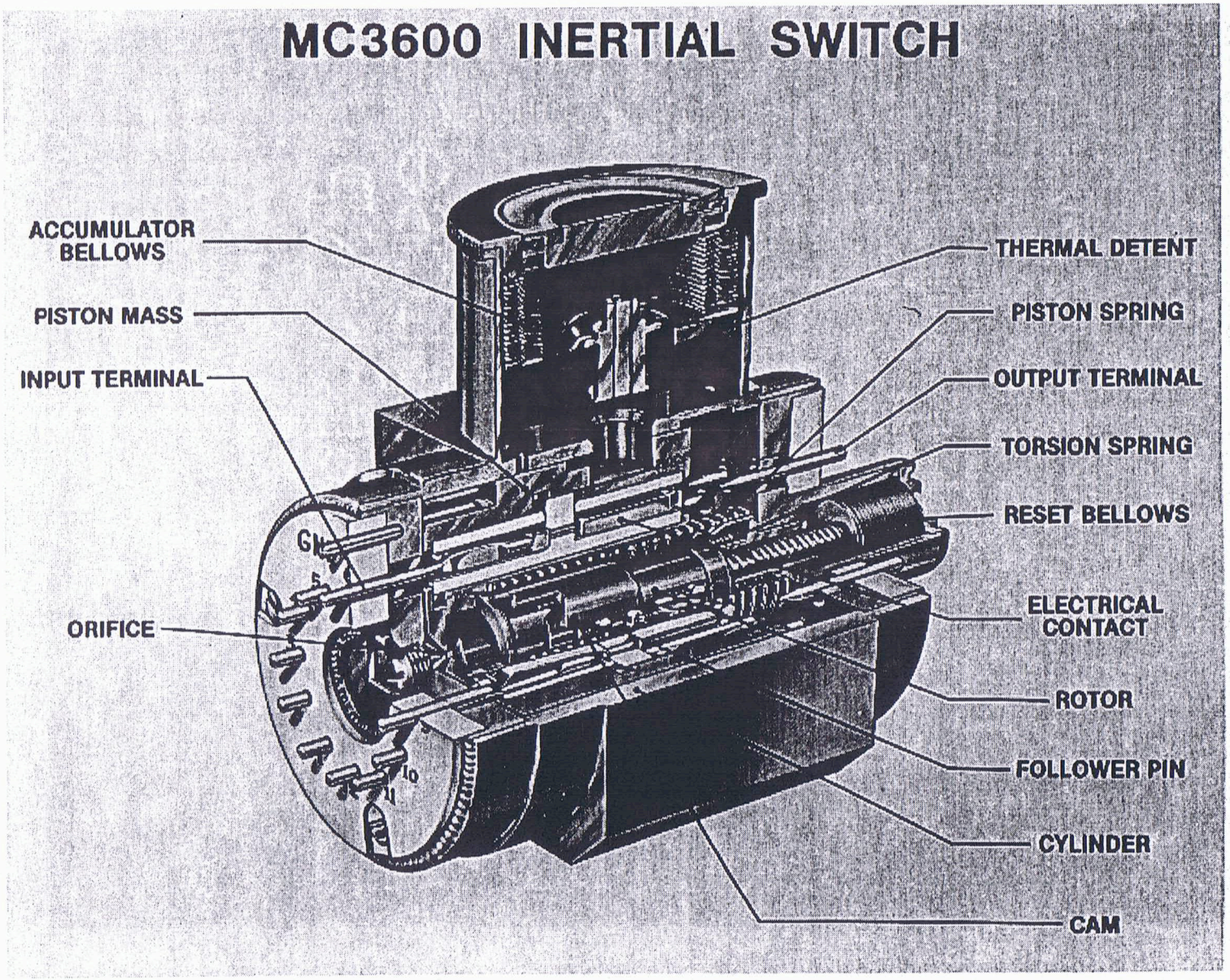
- ***Mechanical*** g-switches & integrating accelerometers
  - Stand-alone inertial fuze or initiation of reentry timer fuze
  - Closure of electrical contacts cause by completion of sensing mass travel
  - Features to attain minimum g's and g-seconds
    - Fluid-metering
    - Escapement mechanism
  - Mechanical feature variations limit accuracy to 1%
  - Extensive use as nuclear safety switches

- ***Electronic*** integrating accelerometers
  - Stand-alone inertial fuze or part of "path length" mechanization
  - Control circuitry generates "restoring current" proportional to acceleration
  - Provides continuous measurement of integrated deceleration
  - Electrical circuit tolerancing controls accuracy to 0.1%

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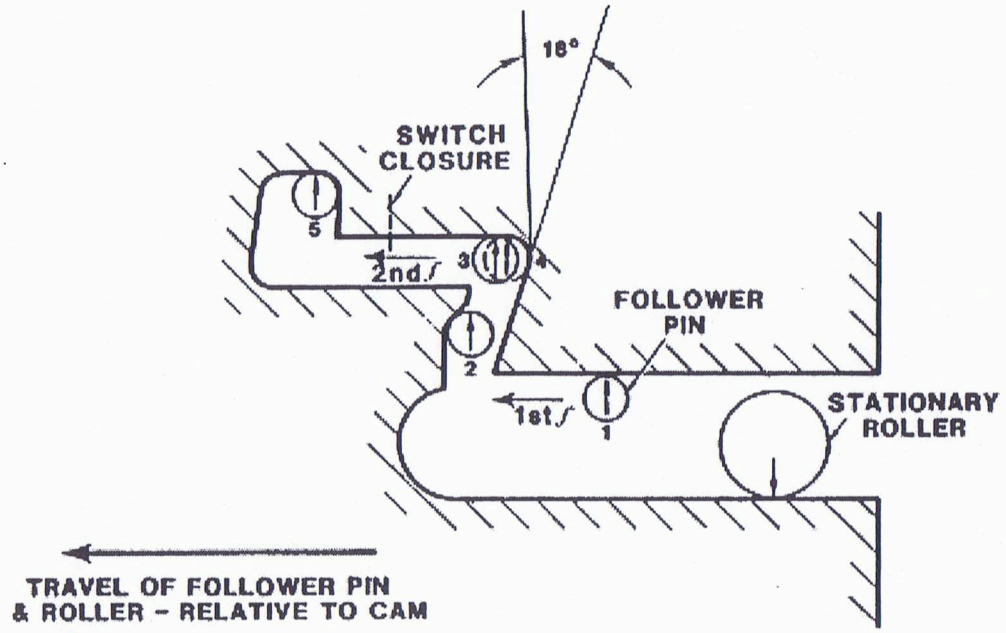

MC2913
INCHES
MM

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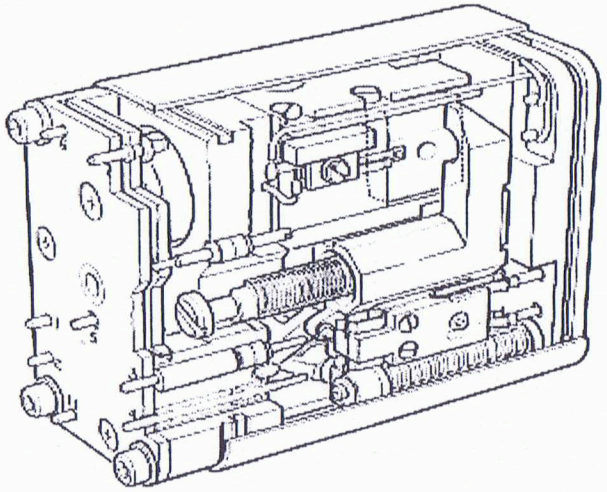


TWO-STAGE CAM SCHEMATIC

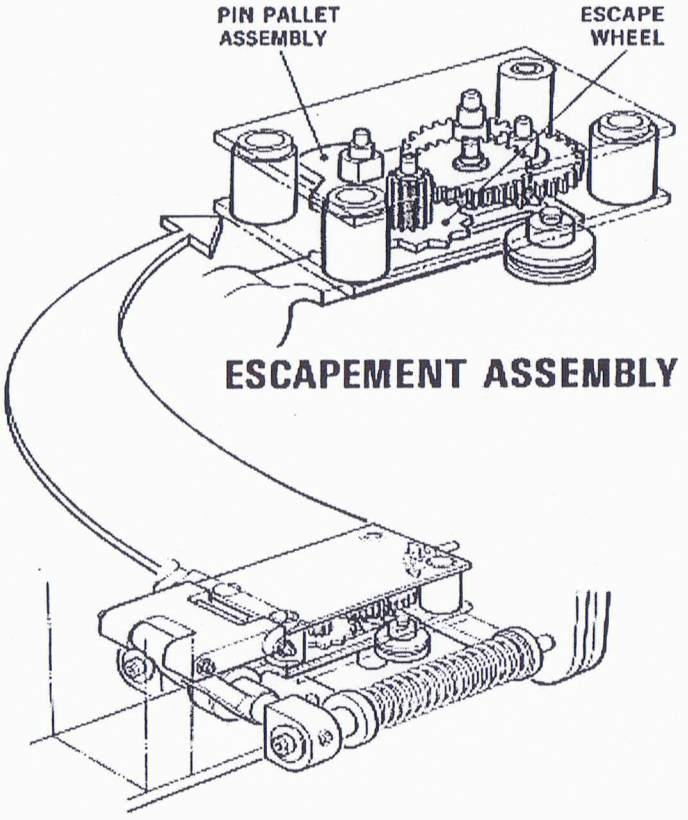
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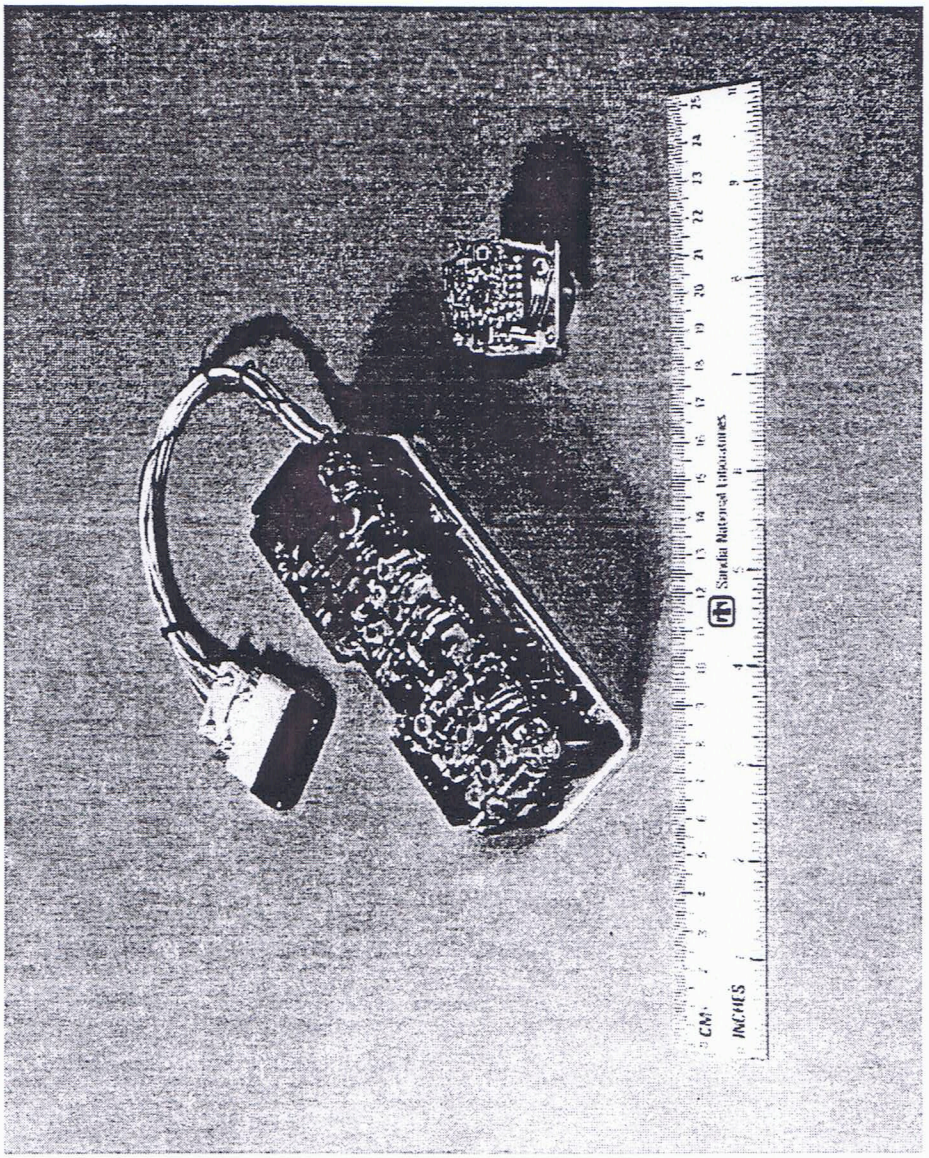
MC 2897 INERTIAL SWITCH



ESCAPEMENT ASSEMBLY

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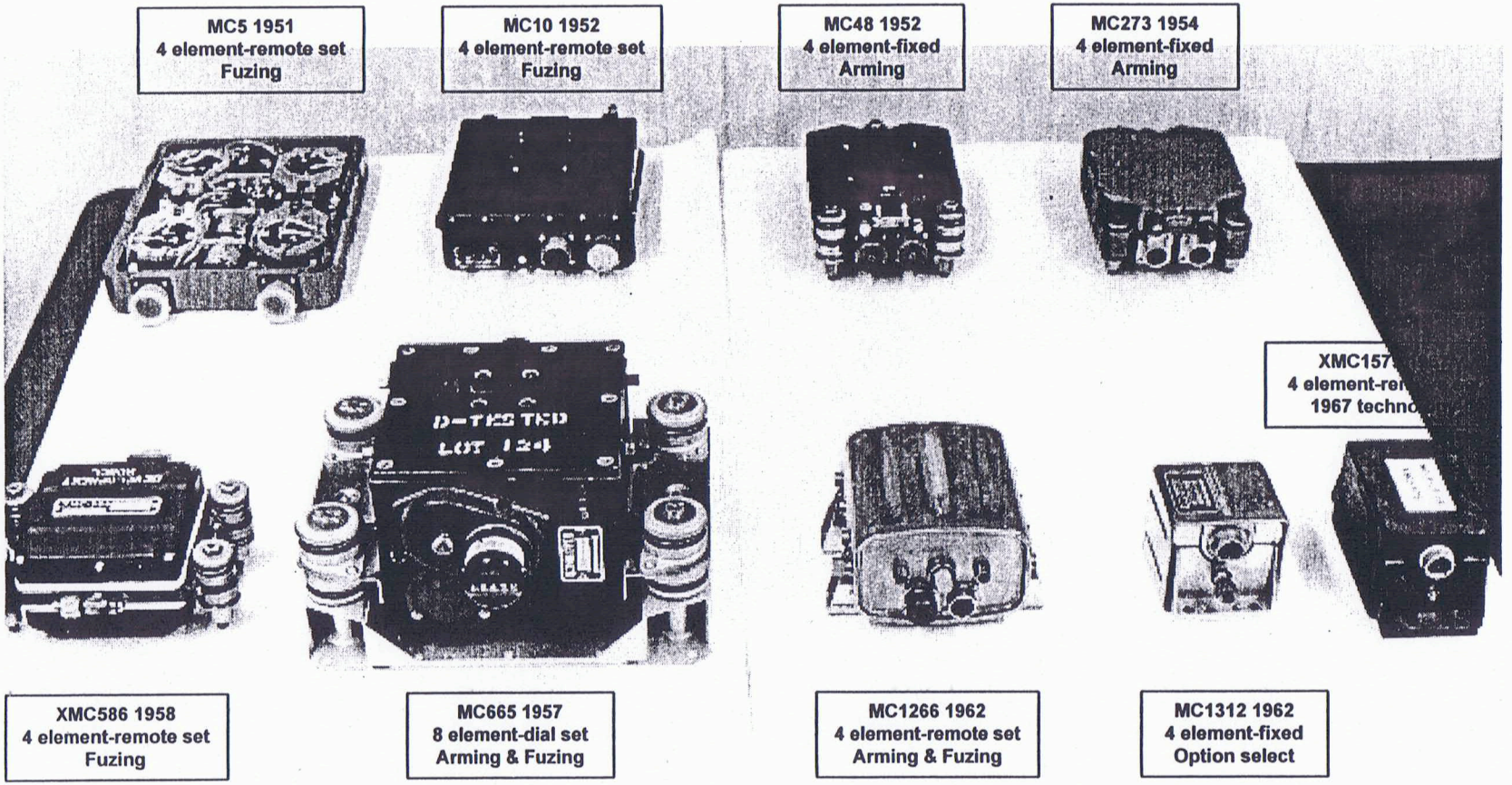

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QUARTZ CRYSTAL ACCELERATION SENSOR

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Barometric Switches



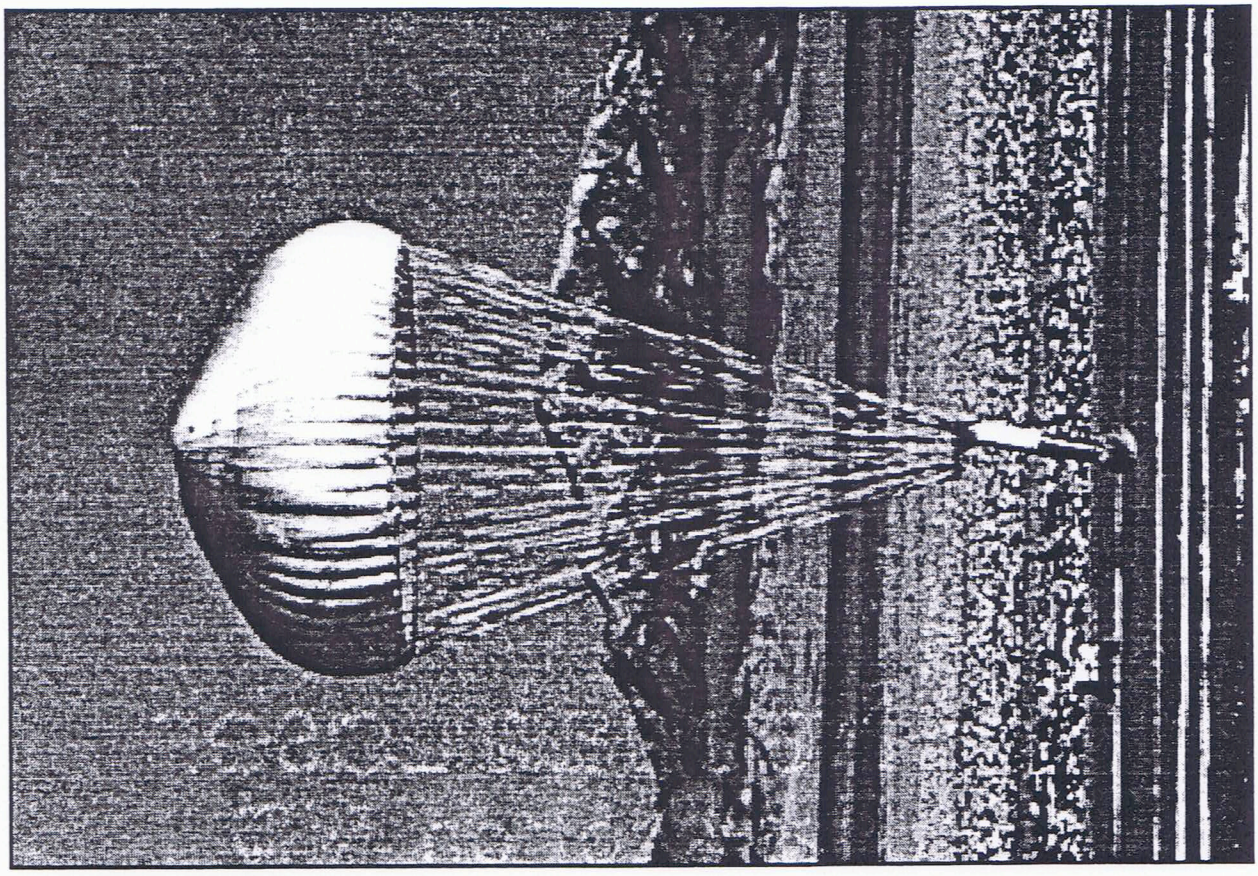
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Timers

- Reentry body fuzing
  - Primary fuze on older systems
  - High altitude fuze and/or backup to radar on recent systems
  - Candidate fuze for earth penetrating weapons
- Bomb fuzing
  - Also uses timer for safe escape in laydown mode
- Artillary projectiles and special munitions
- Depth bombs
  - Timer initiated by water impact or hydrostatic pressure

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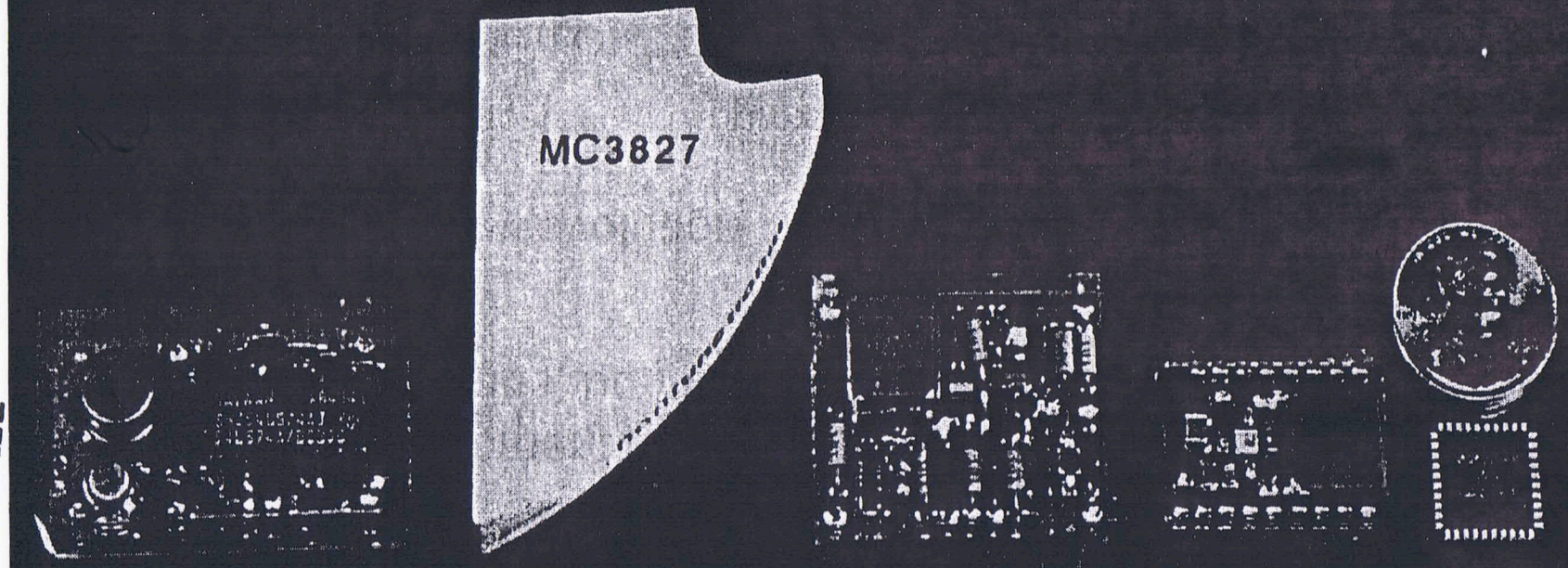
Timers (cont'd)

- Mechanism for initiating arming functions, I.e., batteries
- Critical element of any programmer and/or computer for warheads, bombs, guidance platforms, etc.
- Technology evolution
  - Mechanical — Approximately 5% accuracy
  - Electronic (LC) — Smaller with approximately 2% accuracy
  - Crystal — Smallest with accuracy measured in parts million

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Some Clocks In Stockpile



MC3648
B61-7

MC3827
Trident II

MC4178
B61JTA

MC4081
B61-3,4,10

MC3852
Code
Activated
Processor

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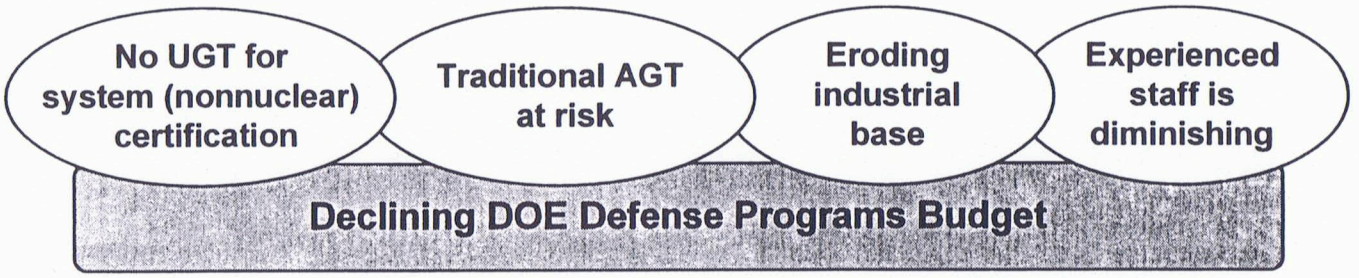
b (3)

Stockpile Stewardship will require Maintenance, Refurbishment & Repair

Future:

- Performance certification (both current & new)
- Design & manufacturing (when required)

Environment:



Current need:

- Stockpile design options
- Capability sustainment

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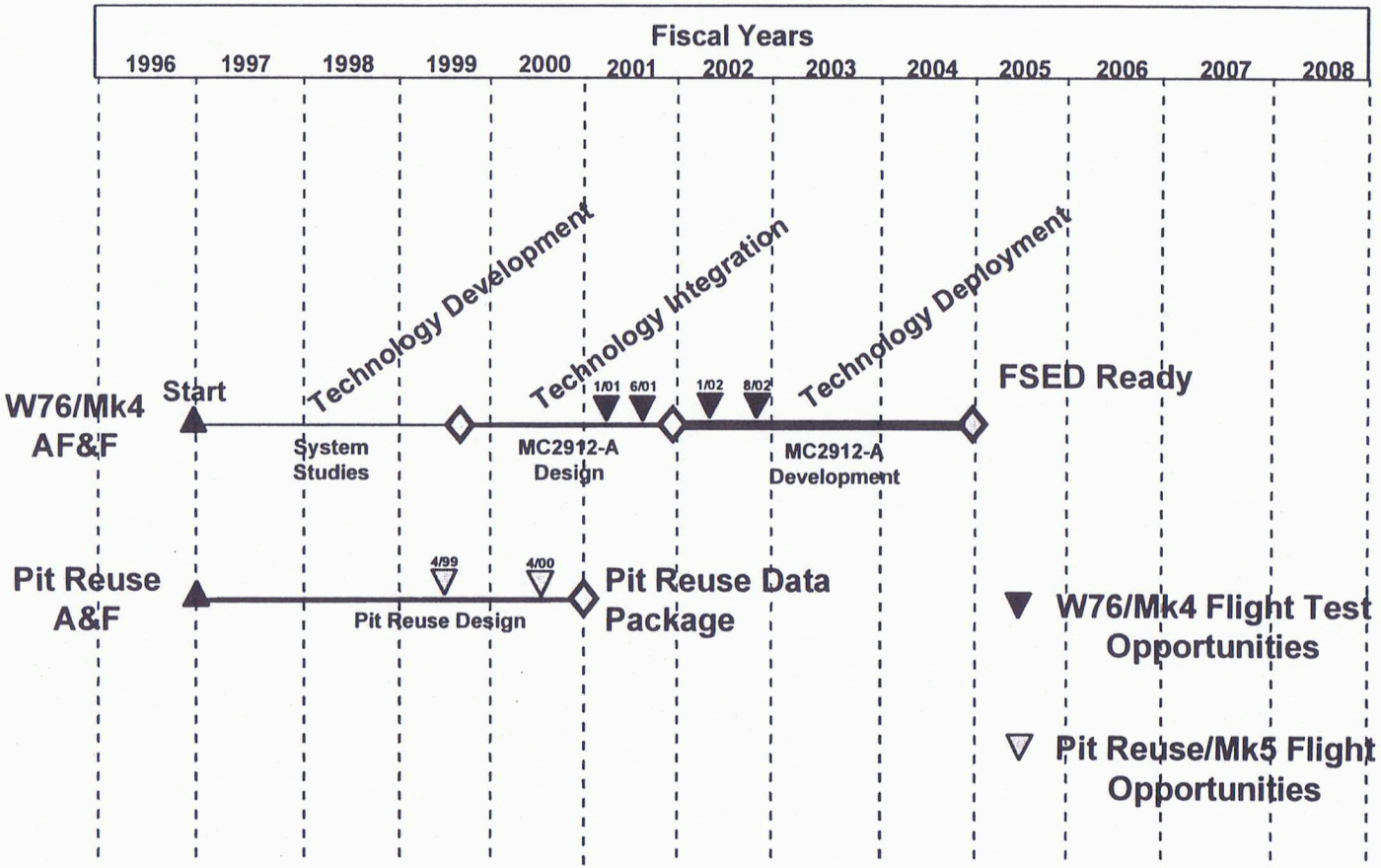
SWPP DoD/DOE MOU (draft)

- Purpose for MOU
  - Program authorization
  - Roles & responsibilities
- Program Objectives
  - Exercise DOE capabilities relevant to SLBM
  - Demonstrate viability of system & component replacement options for W76 & W88
  - Emphasis on non-producible hardware and development of certification methods
  - Does not include fabrication of stockpile hardware
- Deliverable
  - Design Data Package for each option -- design definition, manufacturing & certification feasibility, identification of subsequent activities

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Reentry systems advanced AF&F project



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Fuzing options for replacement Mk4 AF&F

Mk4

- airburst radar, 3 ranges
- inertial airburst, g-started timer
- contact backup

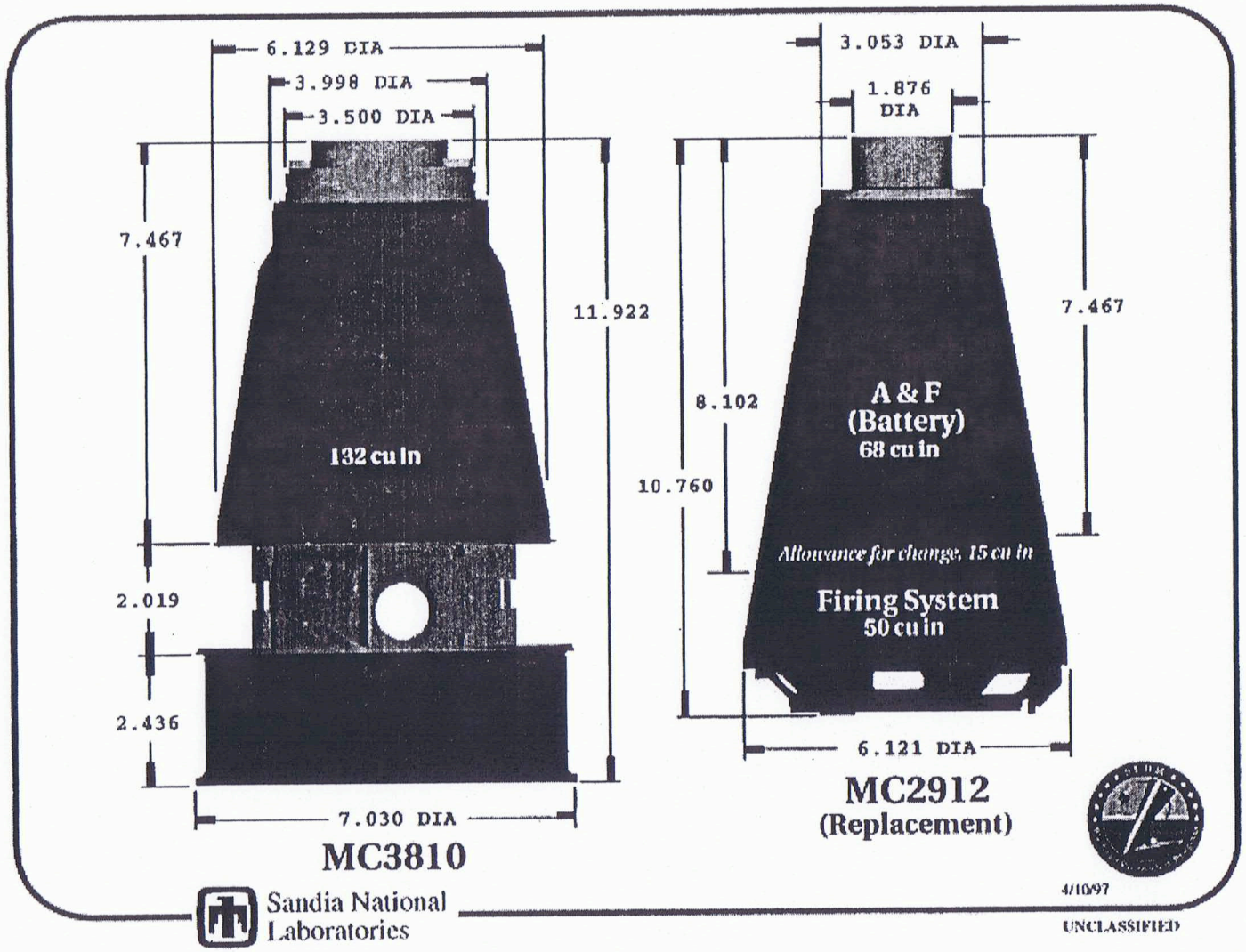
Mk5

- radar-update path length (RUPL)
- airburst radar, 5 ranges
- inertial airburst, path length
- high airburst, timer
- proximity radar
- contact backup

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Fuzing options for replacement Mk4 AF&F

- eliminate long-life thermal battery
- dormant electronics during coast
- minimum perturbation to existing antennas & RF system
- reduced clock accuracy requirements
- reduced inertial sensor accuracy requirements
- simplified processing
- reduced non-volatile memory requirements
- nuclear safety upgrades enabled →
- improved instrumentation →
- dependable surface fuzing →
- new fuzing option for Mk4 →
- ***reduced development & production costs***

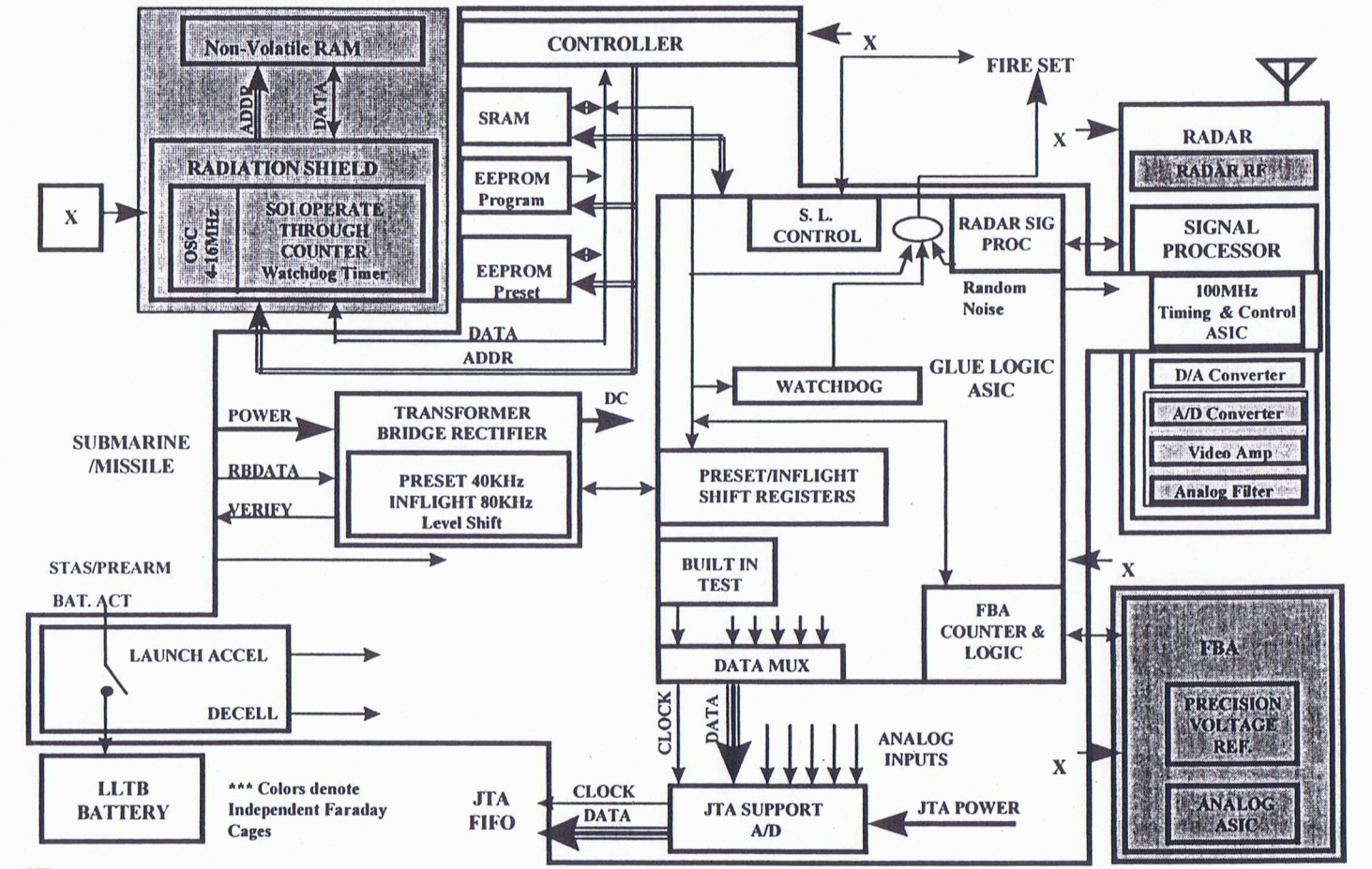
Mk4

Mk5

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A&F architecture to support W76/Mk4 and Pit Reuse



Sandia National Laboratories

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The following information is for reference only

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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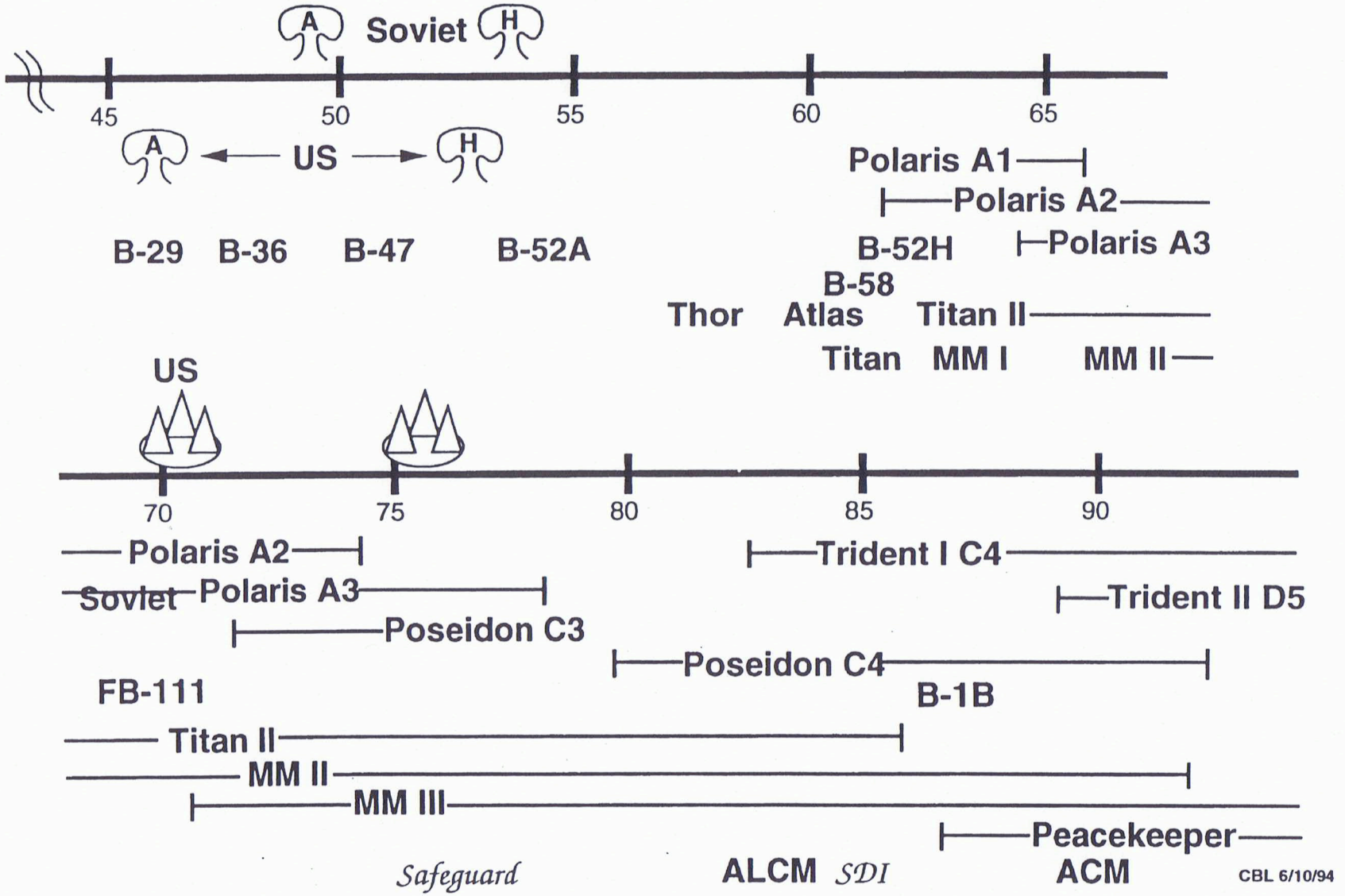
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SESSION XV

- ARMS CONTROL ISSUES

Strategic Delivery Systems



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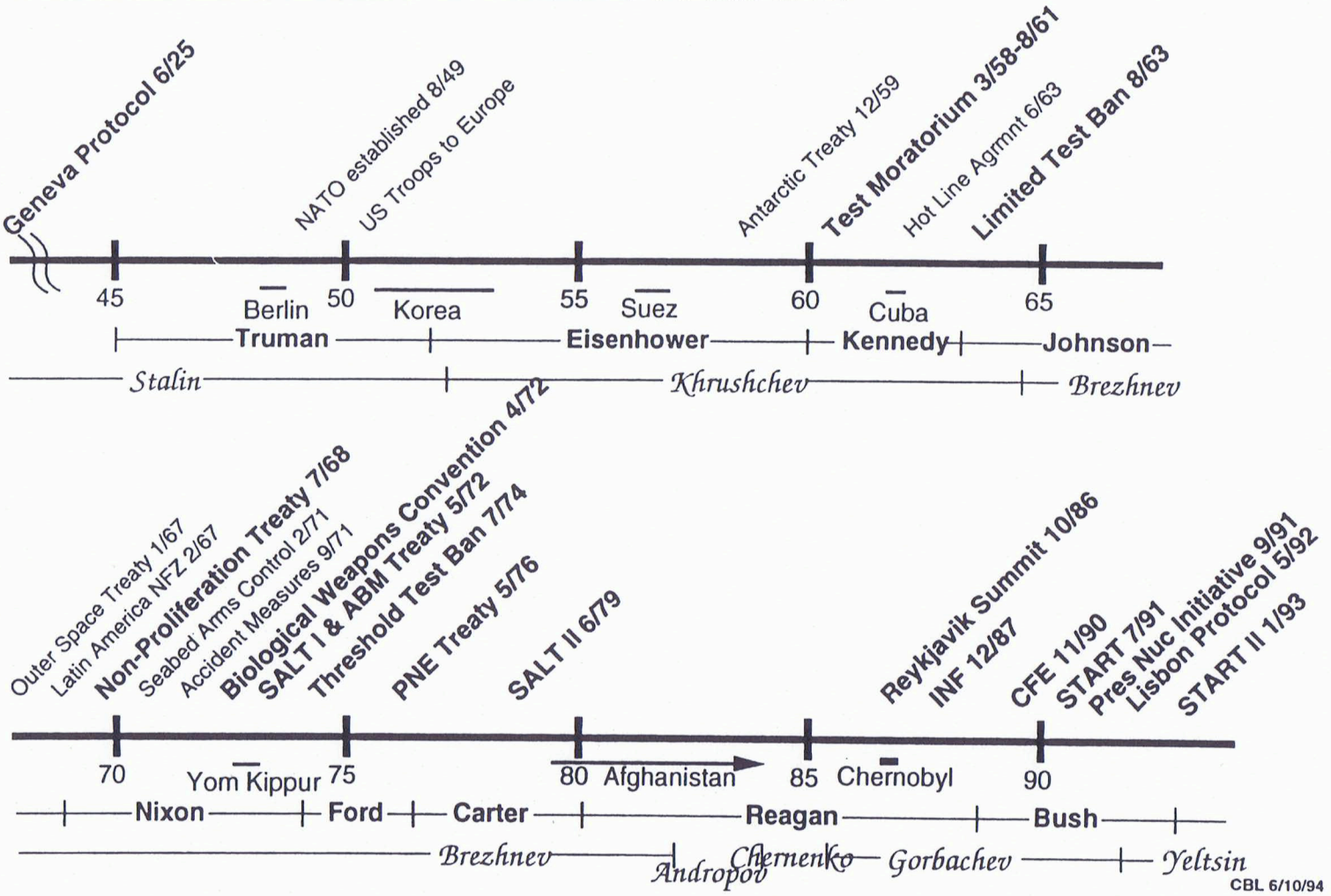
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The Evolution of Response Time

1948	Berlin blockade	2 days to assemble
1957	Suez	few hours to launch
1959	DEFCON established	
1960	JSTPS & SIOP	1/3 of bombers ready for immediate take-off
1962	Cuban missile crisis	1/8 on airborne alert

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Arms Control Treaties



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The Geneva Protocol - 1925

Banned the use in war of asphyxiating, poisonous, or other gases and of bacteriological methods of warfare

US ratified in 1975

All major states now parties

UN Conference on Disarmament is working toward a ban on production and stockpiling

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Test Moratorium - 1958 to 1961

In March 1958, Soviets declared moratorium

In October, negotiations on CTBT began & Eisenhower announced 1-yr U. S. moratorium

May 1960 U-2 incident scrubbed planned summit

Kennedy Administration resumed talks

August 1961, citing French test, Soviets resumed testing

Soviets conducted over 50 tests in the last 3 months of 1961

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The Limited Test Ban Treaty - 1963

Limited nuclear tests to underground

Original signatories were US, Soviet Union, and UK

US ratified 10/63

More than 100 parties now

France ceased above ground tests in 1974,
China in 1980

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The Nonproliferation Treaty - 1968

- Eisenhower proposed "Atoms for Peace" in 1953
- IAEA established in 1957 to promote and monitor
- Nuclear Nonproliferation Treaty was negotiated from 1965 and signed in 1968
- NPT Review Conferences every 5 years
- After 25 years (April 1995) the Review and Extension Conference (Chaired by Amb. Dhanapala) decided on indefinite extension - without a vote
- In exchange for peaceful use of atomic energy, signatories agree to safeguards

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States not party to the NPT (as of 1/23/97)

- Brazil
- Cuba
- India
- Israel
- Macedonia
- Pakistan
- Serbia/Montenegro

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CBL 5/28/97

Biological and Toxin Weapons Convention

Outlaws development, production, stockpiling of all biological or toxin weapons and requires destruction of existing stocks

No specific verification provisions

Signed in 1972 and ratified by the US in 1975

Nixon ended US program in 1969 and destroyed stocks

Soviet incident at Sverdlovsk in 1979

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SALT I - 1972

Interim Agreement on Strategic Offensive Arms

Limited launchers (silos and sub tubes) to the then current number

US - 1710 SU - 2347

Limit on heavy launchers (SS-9 and later SS-18)

Five year duration

US ratified in Oct 1972

Reagan repudiated SALT I and II in May 1986

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Joint Statement on the ABM Treaty - March 21, 1997

- Preserve the ABM Treaty, prevent circumvention, and enhance viability
- TBM systems may be deployed, but must not threaten strategic nuclear forces
- TBM systems will not be deployed against each other (?)
- SCC to complete demarcation between TBM and ABM
  - target missile velocity < 5 km/s, range < 3500 km
  - no space based TBM interceptors based on OPP

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CBL 5/28/97

ABM Treaty - 1972

Johnson and McNamara tried to convince Kosygin at Glassboro to limit ABM systems - June 1967

US announced Sentinel program in September1967

ABM talks were postponed by Soviet invasion of Czechoslovakia in 1968

Nixon changed concept to Safeguard, protecting ICBMs and Washington, DC

Treaty prevents defense of territory, limits to 2 sites with 100 interceptors, limits LPARS

Forbids mobile ABMS or sea, air, or space systems

OPP, Krasnoyarsk, SCC, capabilities questions

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Threshold Test Ban Treaty - 1974

Signatories are the US, Soviet Union, and UK

Limits nuclear tests to 150kT

Verification by NTM (seismic)

A two page treaty

Joint Verification Experiment in 1988

US ratified in 1989

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Peaceful Nuclear Explosives Treaty - 1976

Limited peaceful nuclear explosives to 150kT

Permitted maximum aggregate yield of 1.5 MT, with on site monitoring for yields above 150kT

Plugged a loophole in the TTBT

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SALT II - 1979

Limited and reduced SNDVs

All SNDVs	2250	(2504 actual)
MIRVed ICSs, SLs, bombers	1320	
MIRVed ICs, SLs	1200	
MIRVed ICs	820	

One new type, no new heavies, MIRV limits

CM counting rules, FRODs, Backfire statement

Verification by NTM, no encryption

12/79 Afghanistan, withdrawn from ratification

"Fatally flawed," no undercut, then terminated 5/86

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Conventional Forces in Europe - 1990

MBFR talks ended after 15 years in February 1989

CFE talks formally opened March 1989, with the 23 members of NATO and the Warsaw Pact

Treaty signed November 1990

Treaty limits equipment in the Atlantic to the Urals (ATTU) region

Limits on tanks, artillery, ACVs, combat aircraft, attack helicopters

Wide-ranging and intrusive verification regime

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START Treaty - 1991

Signed July 31, 1991, 5 months before the end of SU

Lisbon Protocol, signed May 1992, committed Russia, Ukraine, Belarus, and Kazakhstan to START (and NPT)

START limits SNDVs and deployed warheads:

	START	US forces*	Soviet forces*
SNDVs	1600	2246	2500
ICBM & SLBM Warheads	4900	8210	9416
Total Warheads	6000	10563	10271
Heavy ICBM Warheads	1540	------	3080
Mobile ICBM Warheads	1100	------	618
Throw-wt ICs & SLs (metric tons)	3600	2631	6626

*as of 9/90

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Nuclear Posture Review - 9/94

- **Strategic Forces**
  - **No more than 20 B-2 bombers**
  - **Reduce B-52 force from 94 to 66**
  - **Reduce Trident fleet from 18 to 14**
  - **Maintain single RV MM III**
- **Non-Strategic Nuclear Forces**
  - **Maintain European NSNF at current level**
    (<10% of Cold War levels)
  - **Eliminate nuclear weapons capability from surface Navy**
  - **Retain cruise missile capability on subs**
  - **Retain land-based DCA**

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Comprehensive Test Ban Treaty - 200?

- Adopted by the UNGA 9/10/96
  - CD could not reach consensus (India)
- EIF requires 44 states with reactors
  - includes India, Iran, Egypt, Israel, North Korea, Pakistan
- Activities not prohibited - finessed
  - US "true zero" yield
- Zero not verifiable, less than 1kT too expensive
- International Monitoring System
  - Seismic, Radionuclide, Hydroacoustic, Infrasound
  - OSI requires 30 of 51 Executive Council votes

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CBL 5/28/97

START III - 200?

- Clinton and Yeltsin at Helsinki Summit, March 21, 1997
  - Immediate START III negotiations upon START II EIF
  - 2,000 - 2,500 strategic warheads by end of 2007
  - Transparency of strategic warhead inventories
  - Measures to promote irreversibility of warhead reductions
  - Deactivation of SNDVs under START II by end of 2003
  - Elimination deadline for SNDVs extended to end of 2007

Joint Statement on Parameters on Future Reductions in Nuclear Forces

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CBL 5/28/97

The President's Nuclear Initiative-1991

Sept 1991

- Eliminate ground launched tactical nuclear weapons
  - Lance and AFAPs
- Withdraw tactical nuclear weapons from surface ships, subs and P-3 bases
  - B-57, SLCM, B-61
- Stand down strategic bombers from alert
- Stand down MMII
- Cancel mobility for PK and SICBM
- Cancel SRAM II
- Propose joint elimination of MIRVed ICBMs

Jan 1992

- Build only 20 B-2s
- Cancel SICBM
- Halt production of ACM
- Halt production of W88 for Trident II

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START II - 1993

Treaty between the Russian Federation and US, signed by Bush and Yeltsin January 3, 1993, codifed agreements of the Washington summit of June 17, 1992.

START II builds on START - and requires START

	START	START II Ph1	START II Ph Ph2
Start Warheads	6000	3800-4250	3000-3500
ICBM & SLBM Warheads	4900	no sublimit	no sublimit
MIRVed ICBM Warheads	N/A	1200	0
SLBM Warheads	N/A	2160	1700-1750
Heavy ICBM Warheads	1540	650	0
Mobile ICBM Warheads	1100	1100	1100

Phase one to be complete 7 years after entry-into-force,
Phase two by 2003

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Comprehensive Test Ban

- Negotiations ongoing at the UN CD
- China testing through '96
- France resumed (8 tests) 9/95 - 5/96
- Activities not prohibited

  US - "true zero" UK - soon, US codes

  France - OK Russia - eventually

  China - waffling, still wants PNEs
- Zero not verifiable, less than 1kT too expensive
- International Monitoring System

  Seismic - 50 stations, 50 - 150 auxiliaries

  Radionuclide - Ba140, 75 - 100 stations, US wants Xe

  Hydroacoustic

  Infrasound - 50 - 60 stations
- Implementing agency - IAEA or ?

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Books of interest

The Making of the Atomic Bomb, Richard Rhodes, 1986.
Pulitzer prize winner, follows the scientific discoveries that led to the bomb, particularly good at the personalities involved, finishes with vivid descriptions of Hiroshima and Nagasaki. Excellent and entertaining.

At the Highest Levels, Michael R. Beschloss and StrobeTalbott, 1993.
Intimate details of the end of the Cold War, as seen at the top.

Lenin's Tomb, David Remnick, 1993.
Details the end of the Soviet Union from the viewpoint of the Russian people and their legacy. Choppy, but a very human picture of the great event.

The Wizards of Armageddon, Fred Kaplan, 1983.
Follows the policy and strategy decision regarding nuclear weapons, much emphasis on the early RAND personalities. Very good and readable.

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Nonproliferation

A New Challenge to the US Nuclear Weapon Program

SESSIONS XVI
John Taylor
National Security Policy Research Department
Sandia National Laboratories

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Some Definitions

Proliferation is the spread of weapons of mass destruction (WMD)-- typically nuclear, biological, and chemical weapons--and the systems which deliver them.

Nonproliferation is the use of the full range of political, economic and military tools to prevent proliferation, reverse it diplomatically, or protect our interest against an opponent armed with WMD or missiles.

Counterproliferation measures are the activities of the DoD across the full range of U.S. efforts to combat proliferation.

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The Changing Context

Old	New
Bipolar Rigidity	Multipolar Complexity
Predictable	Uncertain
Communism	Nationalism/Religious Extremists
U.S. Dominant Western Power	U.S. Militarily No.1 - Not Economical
Fixed Alliances	Ad Hoc Coalitions
"Good Guys and Bad Guys"	"Grey Guys"
U.N. Paralyzed	U.N. Viable

Ref.: National Security in the 1990s: Defining a New Basis for U.S. Military Forces, Rep. Les Aspin, Chrmn House Armed Services Committee, January 6, 1992

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Nonproliferation Initiative

The Changing Threat

Old	New
Single (Soviet)	Diverse
Survival at Stake	American Interests at Stake
Known	Unknown
Deterrable	Non-Deterrable
Strategic Use of Nukes	Terroristic Use of Nukes
Overt	Covert
Europe-Centered	Regional, Ill-Defined
High Risk of Escalation	Little Risk of Escalation

Ref.: National Security in the 1990s: Defining a New Basis for U.S. Military Forces, Rep. Les Aspin, Chrmn House Armed Services Committee, January 6, 1992

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A Snapshot of the World

- 253 Sovereign nations, dependent areas, etc.
- 189 (±) Countries
- 177 Members in the United Nations
- (171 Members in FIFA!)

- 60 conflicts in progress involving more than 130 states or subnational entities

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All the World's Conflicts - May 1996

Area	Countries	Intensity	Nature of Conflict

Summary and Analysis

Intensity by type and percent of total

High	1	(0)	1%	(0%)
Medium	17	(18)	28%	(30%)
Low	42	(40)	71%	(70%)
Totals	60	(58)		

Numbers in ( ) from last reporting period (2/96).





Number and Percentage by Conflict Type

Territory	15	28%
Ethnic	31	53%
Oil	4	7%
Civil War	30	52%
Religious	9	16%

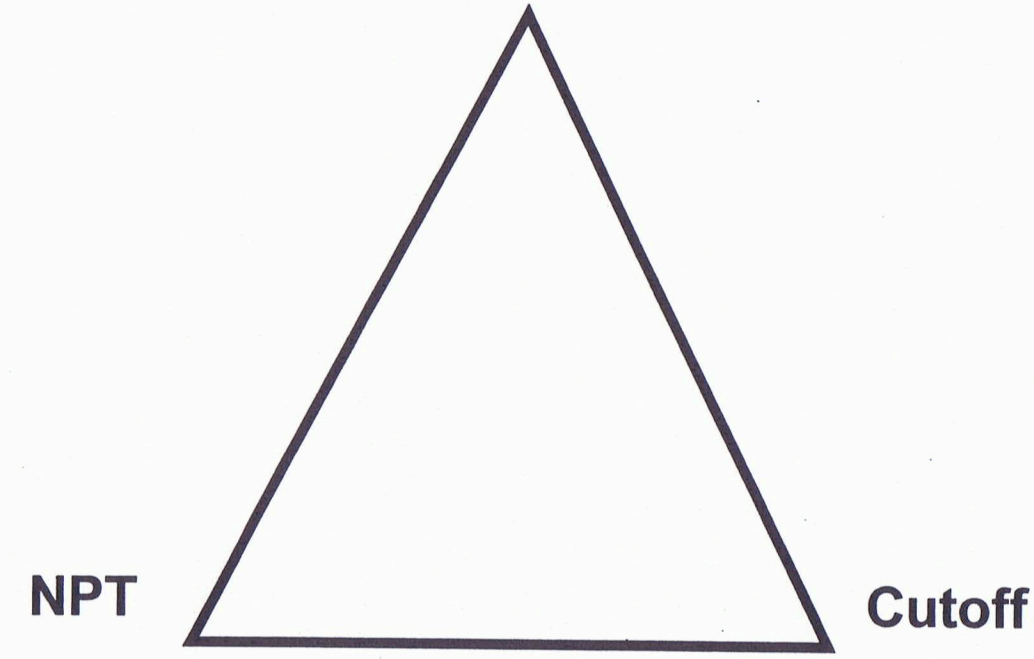
Percent of Total by Region

Europe	12%
Latin America	19%
Africa	31%
Middle/Near East	12%
South Asia	8%
Southeast Asia	7%
Far East	10%



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Alva Myrdahl's Historical View of Nuclear Weapon Controls



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Nonproliferation Initiative

What Constitutes a Weapon of Mass Destruction

- Indiscriminate nature of use
- Effect not confined to belligerents
- Excessive injury -- "cruel and unusual"
- Inability to defend against effectively
- Use would overwhelm medical and evacuation resources
- Notion of "terror"

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Motivation to Acquire Weapons of Mass Destruction

Great Powers have always countered the weapons of other great powers (e.g., USSR in the late 1940s)

Fear that a great power ally will not follow through (e.g., UK, France)

Fear over nuclear capabilities of potential adversaries (e.g., PRC, India, Pakistan, Iran, perhaps US in 1940s)

Fear of adversaries conventional strength (e.g., Israel, perhaps US in 1940s)

Cheaper than conventional defense (e.g., US in 1950s)

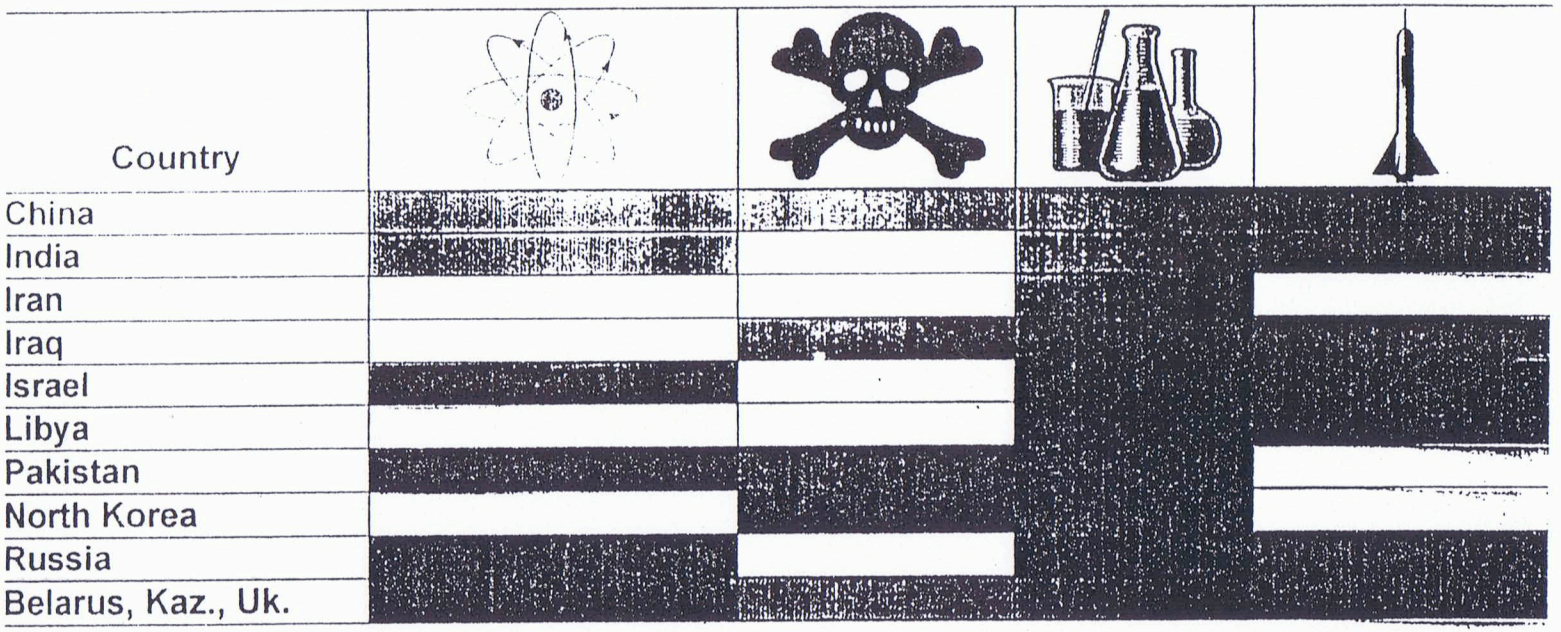
Desire for offensive capability (e.g., US in 1940s?)

Status in world or region (e.g., Iraq)

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Some Proliferants of Concern



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"Cost Effectiveness" of Weapons of Mass Destruction

The cost of producing, storing and delivering weapons can be estimated as the amount of money to deliver one lethal dose.

For nuclear weapons = $2000

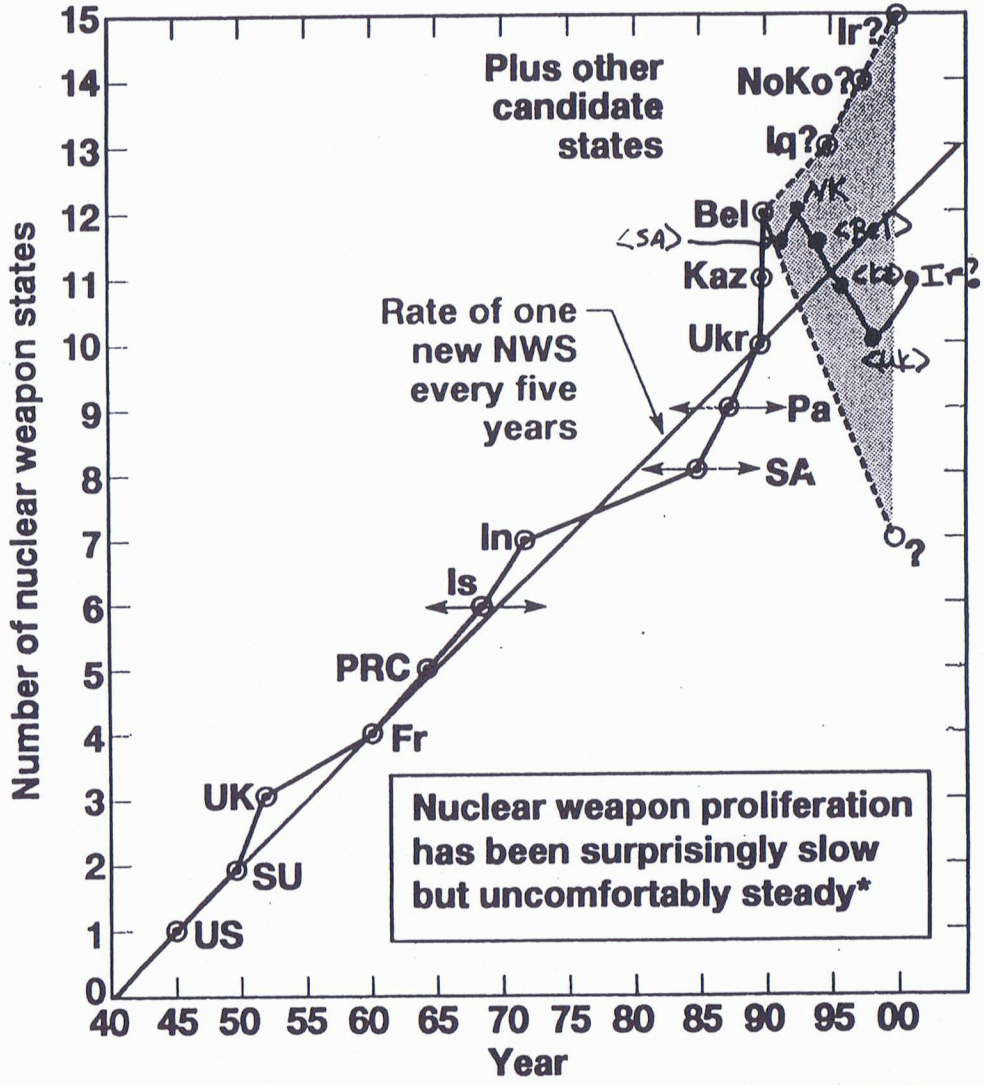
For chemical weapons = $100

For biological weapons = $1

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How many nuclear weapons states will there be in the year 2000?



*Data from news and journal articles in 1992

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Nuclear Proliferation: A Current Status

- Acknowledged/Declared Nuclear Weapon States
  -- US, UK, China, France, Russia
- Undeclared but widely suspected Nuclear Weapon States
  -- India, Pakistan, Israel
- "Inheritors" of Soviet weapons
  --Ukraine, Kazakhstan, Belarus
- Virtual Nuclear Weapon States (e.g., weapon capabilities but no weapons)
  --Japan, Germany
- Threshold Nuclear Weapon States
  --North Korea
- Aspiring Proliferators
  --Iraq, Iran, Libya, Algeria, various terrorist organizations
- Rollback cases
  --Argentina, Brazil, Sweden, Switzerland, Egypt, Taiwan, South Africa(?)

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There have been some Nonproliferation Successes

-- Sweden abandoned its programs in the 1970s.

-- South Africa stopped its programs in 1992 (6 weapons).

-- Argentina and Brazil renounced their programs.

-- Taiwan and South Korea abandoned their programs in the 1980s.

-- Iraq's program "put on hold" by Desert Storm and UN Resolution 687 and 715.

-- Belarus, Kazakhstan, and Ukraine (?) have agreed to return the FSU weapons to Russia.

-- NPT indefinitely extended by "pseudo consensus"

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WMD Technological Capabilities

Nuclear:

5 acknowledged possessors, 30 countries with "capability"

Chemical:

20-24 possessors, 80-90 countries and some subnational entities with "capability"

Biological:

10-12 possessors, virtually every state and several subnational entities are "capable"

(Conventional weapons:

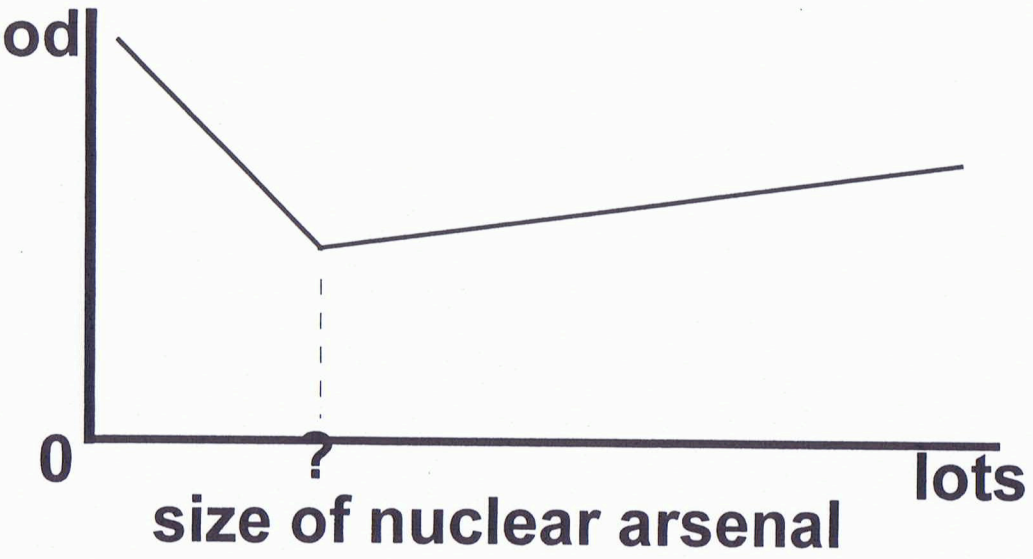
virtually every country possess, 10-40 are major suppliers)

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Why Not Zero?

Many nations and individuals want us to completely eliminate weapons -- attractive philosophy but dubious policy:



There may be things worse than nuclear weapons (e.g. biologics)

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Qualitative Level of Proliferation Concern

Cold War (20,000)

START I (10,000)

START II (5,000±1500)

NAS (1,500)

Zero (0)



In the land of the blind, the one-eyed man is king.

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Nonproliferation Initiative

Options across the Nonproliferation -- Counterproliferation Spectrum

disincentives ⟷ **incentives**

venues

Economics — blockades, sanctions — export controls — foreign aid

Politics — political isolation — int'l organizations — alliances

Military Force — war — peacekeeping — covert operations — military sales — military asst.

confrontation ⟷ **cooperation**

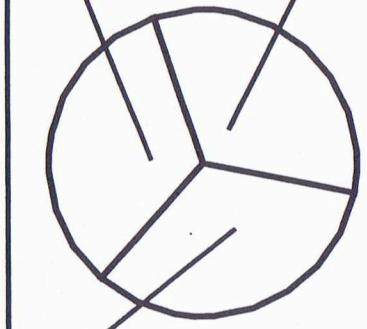
COUNTERPROLIFERATION ⟷ **NONPROLIFERATION**

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Activities Which Accomplish Objectives

Reduce Demand

- International agreements
- Regional security agreements
- Transparency and confidence building
- Responsible behavior by nuclear weapon states
- Penalties for violating international norms
- Minimizing utility



Control Supply

- International Export Control Regimes
- IAEA Safeguards
- Elimination of sources of supply
- Monitoring and enforcement of export controls or embargoes
- Responsible behavior by nuclear weapon states

Mitigate Consequences

- Sanctions and embargoes
- Military activities
- Covert operations

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Nonproliferation Initiative

Goals of Proliferation Controls (non → counter)

-- **REMOVE MOTIVATION** FOR POSSESSION OF NUCLEAR WEAPONS

-- **INTERDICT DEVELOPMENT AND ACQUISITION**

-- **DETER EMPLOYMENT** OF KNOWN OR SUSPECTED STOCKPILES OF NUCLEAR WEAPONS

-- **ELIMINATE INFRASTRUCTURE** BY PERSUASION, INTERNATIONAL SANCTIONS (e.g., Res 687)

-- PROACTIVELY **DESTROY FACILITIES** (e.g., Osirak)

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Secondary Impacts of Nonproliferation Initiatives

- o NPT//NPT Extension Conference (1995):
  - -- Mandates for movement toward global reductions
  - -- Mandate for a CTB by 1996
  - -- Mandate for "FISS_BAN"
  - -- Mandate for Negative Security Assurances
  - -- Improved Safeguards
- o Negotiations on control on fissile materials:
  - -- Codify in-place current US and Russian practices
  - -- Inspection regimes and transparency
  - -- Possible attempts to restrict tritium production
- o Export Controls
  - -- Heightened concern over "dual use" systems and commodities

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Issues on the Nonproliferation platter

-- Control over the nuclear arsenal (and direction) of the FSU

-- North Korea--good deal? bad deal?

-- CTBT--linkage to NPT formalized during EXCON

-- China, France--steadfastly continuing to test

-- The Israeli nuclear arsenal

-- The nuclear relationship between India and Pakistan--imminent missile deployment (M11 vs Prithvi)?

-- Iran--a new reactor (Bushehr) for Israel to target?

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

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SESSION XVII

- STOCKPILE STEWARDSHIP
- SUMMARY/DISCUSSION

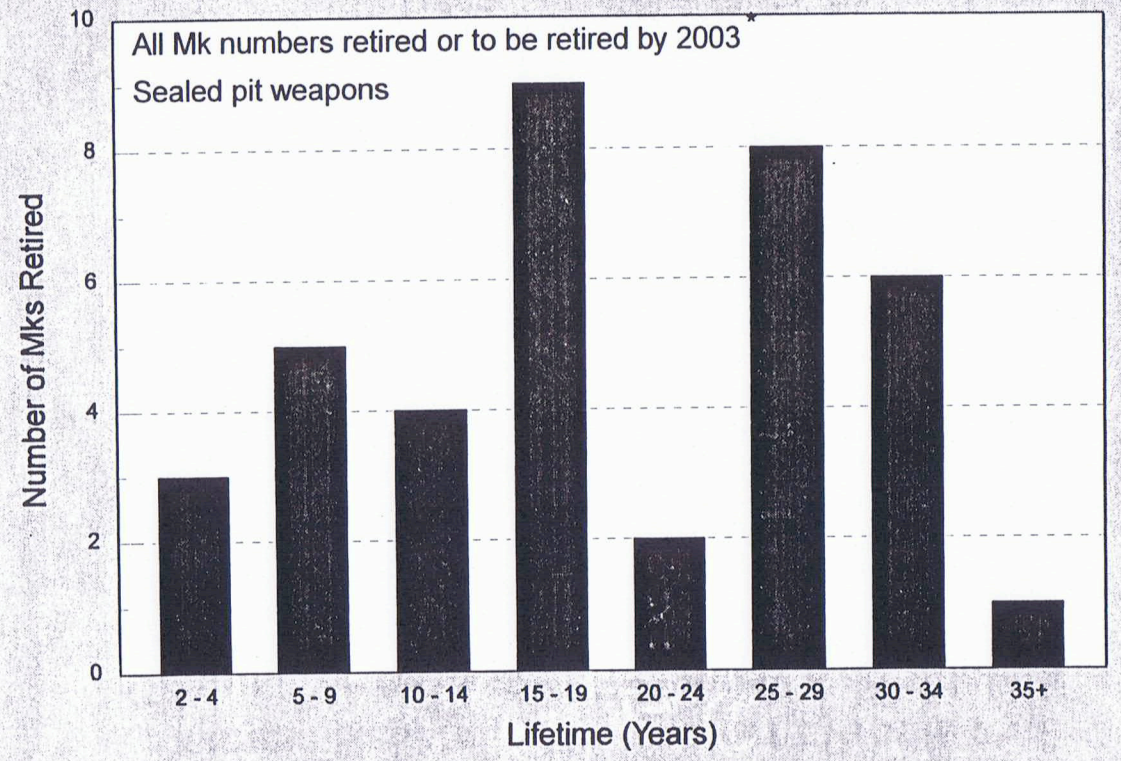
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Mk Number Lifetime



* As projected by P&PD 94-0

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Weapon Histories Lead to a New Question

- "What is required to sustain a weapon while it is in the stockpile?"
  - The DOE has active programs to:

    Upgrade a weapon's surety

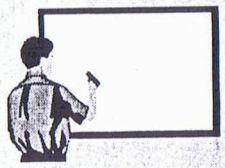
    Maintain a weapon's reliability

    Incorporate new operational features into a weapon

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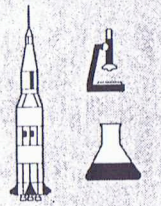
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How Changes Are Made To Stockpiled Weapons



New Surety Concepts

Surety Upgrades



Defects are Discovered

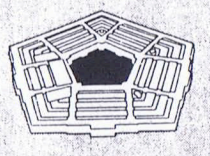
Defect Fixes

Defect Noted No Action Taken

PCP

Product Change Proposal

MODs ALTs & Other Changes



New User Requirements *

Change in Operational Capability

Some MC changes do not involve a PCP

* New user requirements may result in new weapon development

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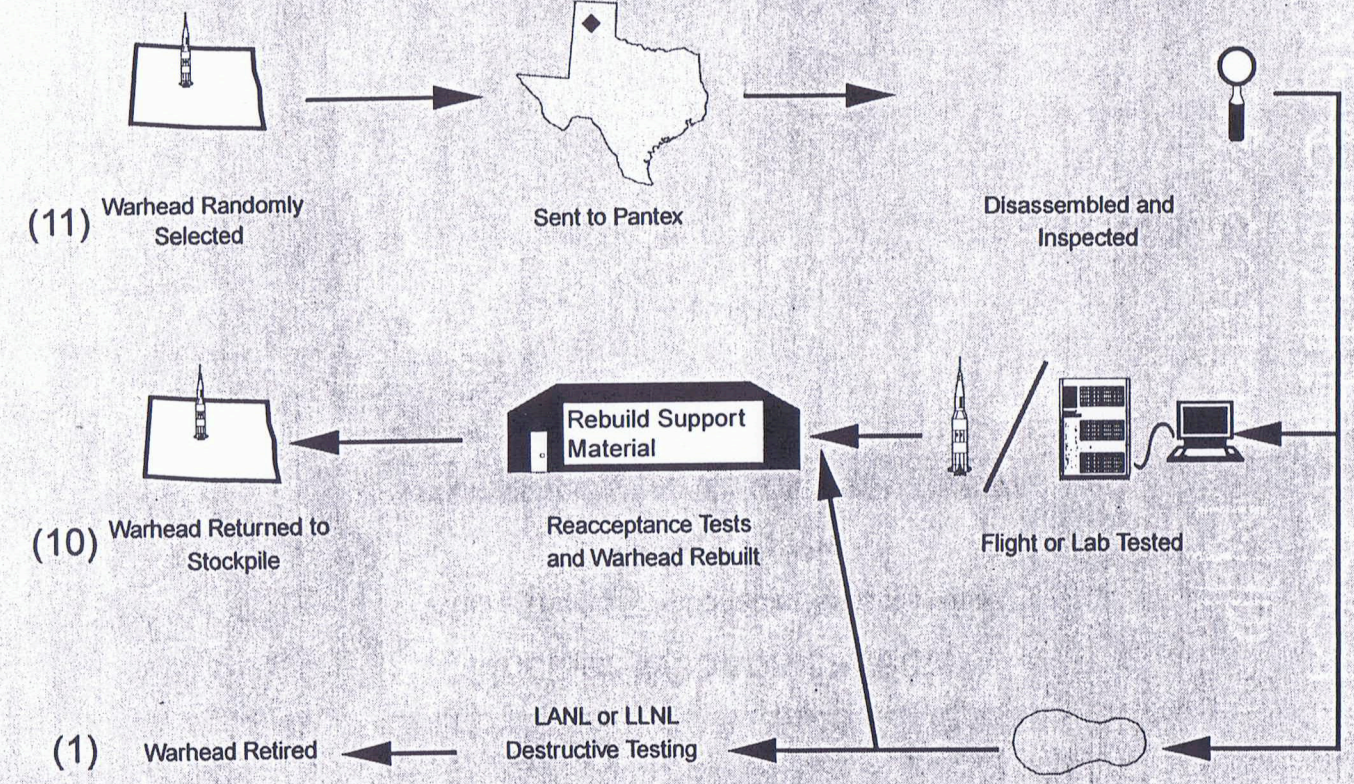
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The Stockpile Evaluation Process

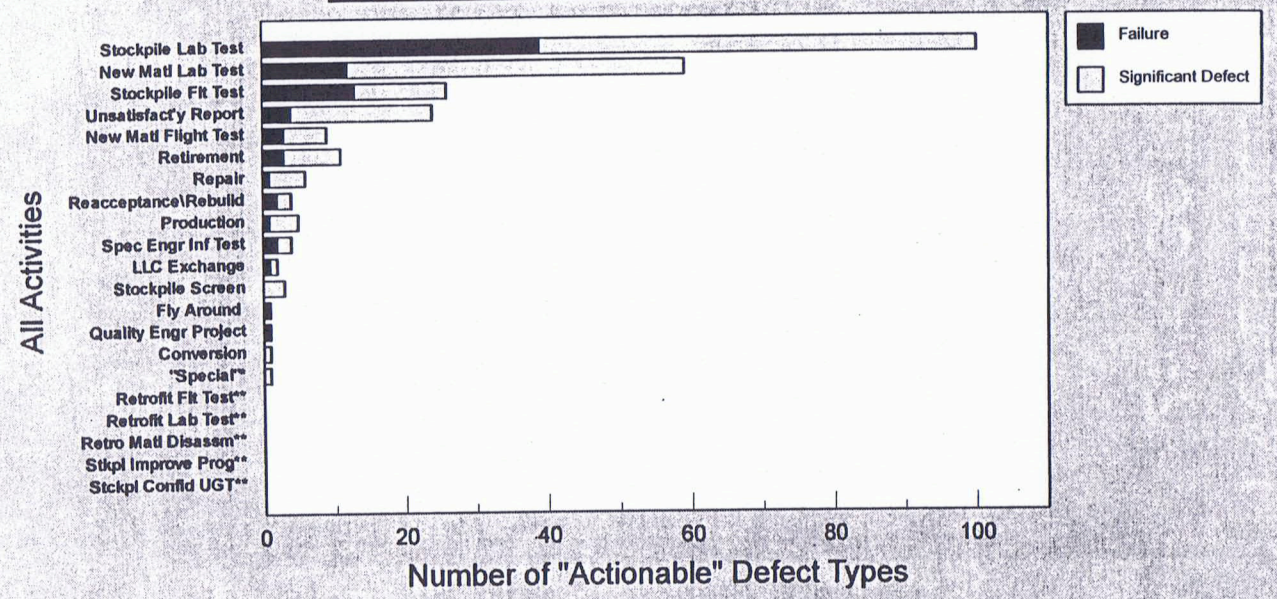


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Nuclear Weapon Defects

Where The 257 "Actionable" Defect Types Were First Discovered



* Designation in the Historical Summary

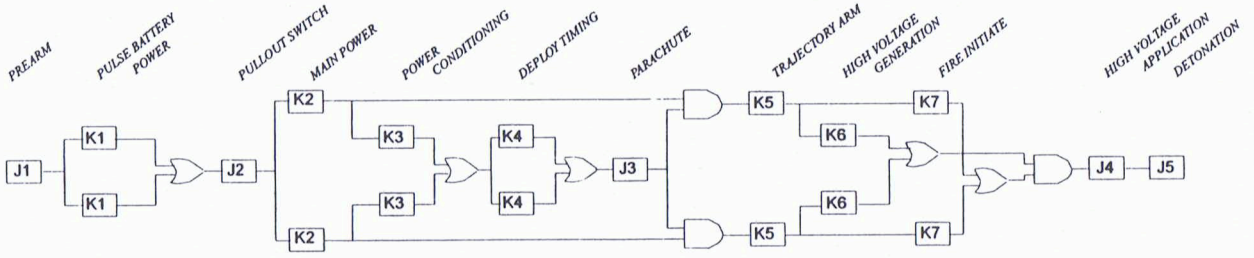
** No "Actionable" Defect Types first discovered

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Reliability Impact Assessed For All Defects

- CONTINUAL PROCESS TO DEFINE WEAPON RELIABILITY -

- Reliability assessment first established during weapon development
  - Reliability model developed



  - Sandia + Physics Lab inputs
- Reliability impact assessed during formal defect investigation (SFI)
  - Data collected from relevant sources
  - Added to existing data base
  - New assessment made (some defects assessed with no reliability impact)

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PCP Includes MOD & ALT

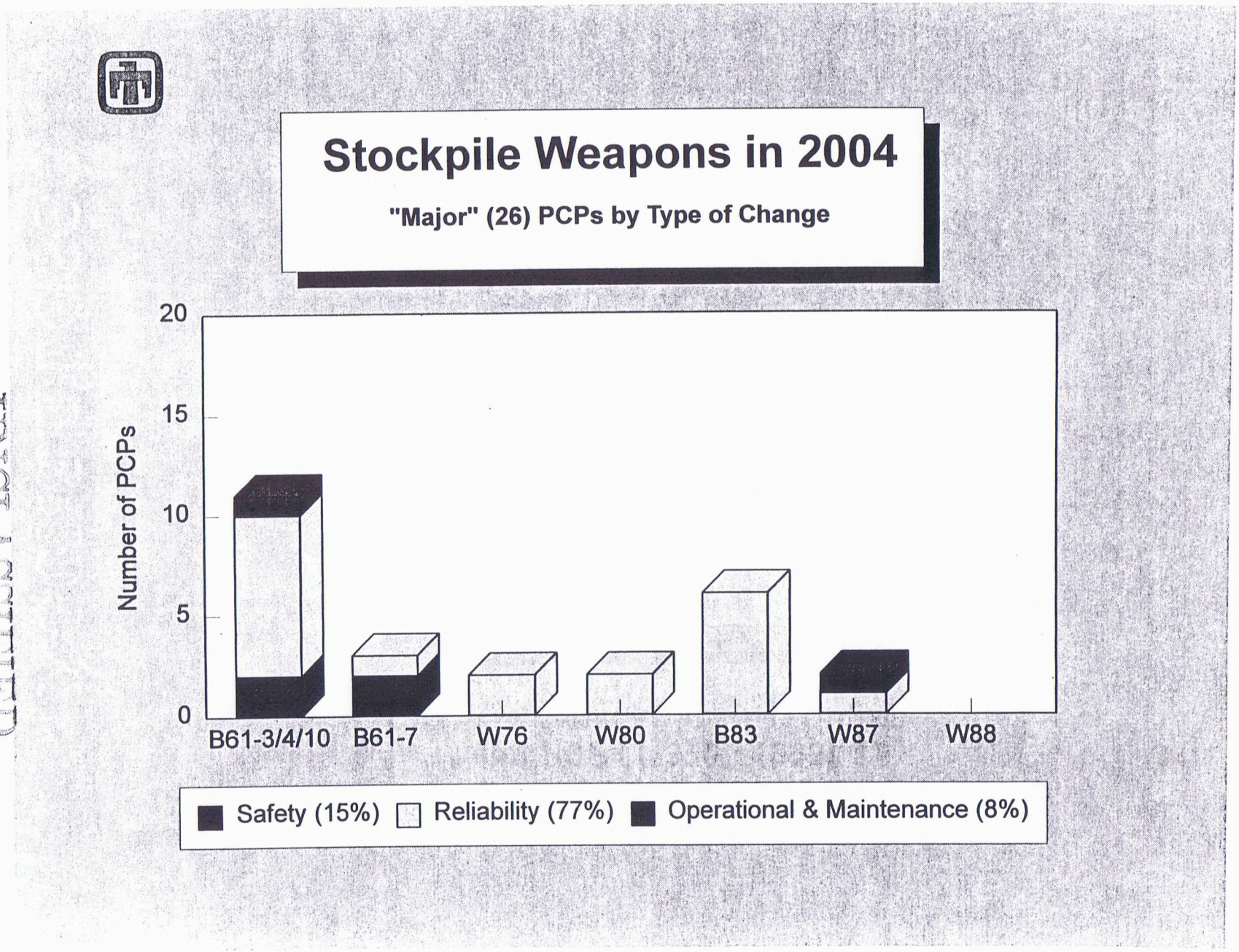
- Product Change Proposal (PCP)
  - Initiates & authorizes any accountable change to a War-Reserve (WR) weapon & its associated gear or non-WR units
  - Range in importance from Change in Wrench (H1324 for the W71)
  - Normally includes MOD & ALT
- Modification Number (MOD)
  - Assigned to any change to a WR weapon that alters its operational capability
- Alteration Number (ALT)
  - Assigned to any accountable change to a WR weapon & its associated gear or non-WR units

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"Major" PCPs (1970 - 1993)

67 PCPs by Type of Change

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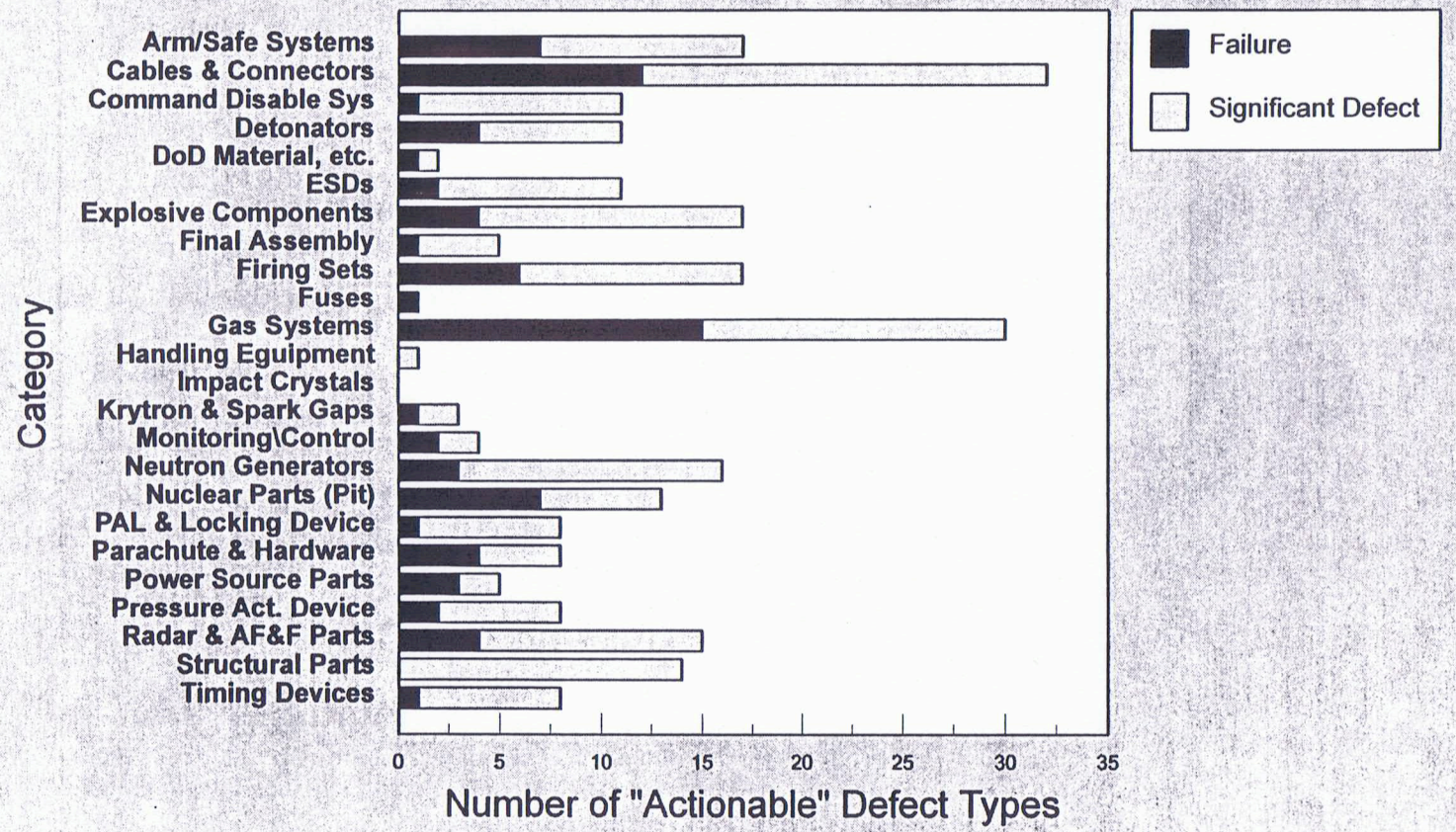
Future Workload Issues

historical data suggest that:

- 1 "actionable" defect will be discovered each year.
- About 2 PCPs will be approved each year - 1 of these will constitute a major change.

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257 "Actionable" Defect Types Grouped By Design Skill Categories



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REFERENCES

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- Individual Weapon Development Reports
- History Of The Nuclear Weapons Stockpile OMA, SRD (1992)
- AL Workload Planning Guidance AWLPG, SRD

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SURVEY OF WEAPONS DEVELOPMENT AND TECHNOLOGY

WR708

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SESSION XVIII

- FIELD TRIP TO THE DEFENSE NUCLEAR WEAPONS SCHOOL'S

WEAPON DISPLAY AREA

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